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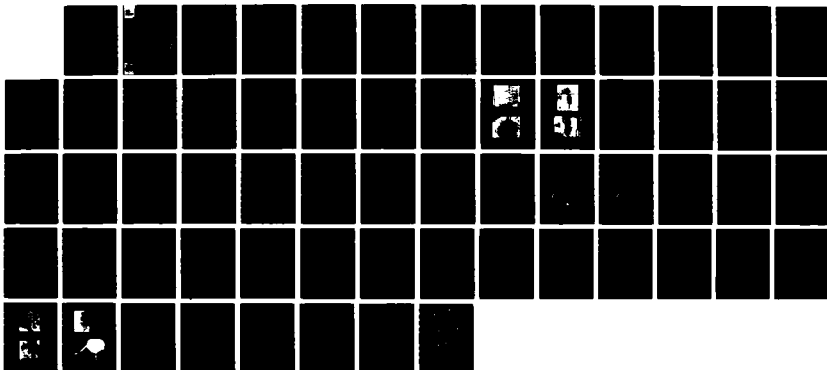
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DEVELOPMENT AND IMPLEMENTATION OF
INSTRUMENTATION FOR WIPP TEST SERIES A
OF THE SMALL-SCALE SEAL
PERFORMANCE TESTS

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DEPARTMENT OF THE ARMY
Army-Waterways Experiment Station, Corps of Engineers
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19. ABSTRACT (Continue on reverse if necessary and identify by block number) <p>An instrumentation program was developed for the purpose of monitoring the state of stress and deformation in a concrete borehole seal for use underground at the WIPP. A laboratory development program was conducted both to select gages for a field experiment and to measure for evaluation purposes the stresses and strains in an expansive salt saturated concrete plug, 3 ft in diameter by 3 ft long, cast in a 34-3/4-in. I.D. by 5-ft-long steel casing with 5/8-in. wall thickness. A total of 33 internal gages were placed in the concrete and 9 gages were located on the external surface of the steel casing. The gages were strategically located to provide the maximum useful information for thermal and structural analysis for the plug. The gages used were: Carlson stress meters; Sandia pressure cells; Carlson strain meters; Ailtech strain meters; SR-4 strain gages; and type T thermocouples.</p> <p>Based on their performance in the laboratory program, gages were selected for</p> <p style="text-align: right;">(Continued)</p>				
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19. ABSTRACT (Continued).

installation in a field experiment at the WIPP. Three vertical boreholes seals, 6-, 16-, and 36-in.-diameter holes were instrumented. Carlson stress meters and Sandia pressure cells were used to measure the stress in the seal. Carlson strain meters and Ailtech strain meters measured the strain in the seal. SR-4 strain gages were fixed to the borehole wall to measure strain at the seal-rock interface. Type E thermocouples were used to measure the temperature in the seal and at the seal-rock interface. The gages were preassembled on a mounting fixture, with the exception of the Carlson joint and stress meters and the SR-4 gages, and positioned in the holes prior to the placement of the concrete. As in the laboratory experiment, the gages were strategically located to provide the optimum description of the concrete seal performance.

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PREFACE

This investigation was conducted for the US Department of Energy under supervision of the Sandia National Laboratories, Albuquerque, New Mexico, as a part of the Small-Scale Seal Performance Tests, Test Series A. Mr. John C. Stormont of Sandia National Laboratories was Technical Monitor. The work was performed at the Concrete Technology Division (CTD), Structures Laboratory (SL), of the US Army Engineer Waterways Experiment Station (WES), and at the Waste Isolation Pilot Plant near Carlsbad, New Mexico.

The investigation was performed under the general supervision of Messrs. Bryant Mather, Chief, SL; J. M. Scanlon, Chief, CTD; and H. T. Thornton, Chief, Evaluation and Monitoring Unit. This report was prepared by D. L. Ainsworth.

The Commander and Director of WES is COL Dwayne G. Lee, CE. Dr. Robert W. Whalin is Technical Director.



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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
inches	25.4	millimetres
pounds (force) per square inch	0.006894757	megapascals
gallons (U.S. liquid)	3.785412	litres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9) (F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9) (F - 32) + 273.15$.

DEVELOPMENT AND IMPLEMENTATION OF INSTRUMENTATION FOR WIPP
TEST SERIES A OF THE SMALL-SCALE SEAL PERFORMANCE TESTS

PART I: INTRODUCTION

Background

1. The Waste Isolation Pilot Plant (WIPP) facility is a research and development facility being developed by the US Department of Energy (DOE) near Carlsbad, New Mexico for the purpose of demonstrating the safe disposal of radioactive waste accumulated from the United States defense programs. The WIPP facility is located in a bedded-salt deposit 2150 ft (656m) below the ground surface. Sandia National Laboratories (SNL) is conducting a repository sealing Research and Development Program at the WIPP facility.

2. The work discussed in this report was in support of Test Series A of the Small-Scale Seal Performance Tests being conducted at the WIPP facility for SNL. The Small-Scale Seal Performance Tests consists of a series of in-situ experiments designed to evaluate the performance of various candidate seal materials emplaced in boreholes in the host rock.

3. At the request of SNL, the Concrete Technology Division (CTD) of Waterways Experiment Station (WES) developed an instrumentation program of sufficient magnitude to support the thermal and structural studies of the concrete seal to rock system being conducted for SNL by others at CTD WES and SNL. The test program consisted of two phases: a laboratory mockup of the Test Series A configuration, conducted at WES; and a Test Series A field experiment, conducted underground at the WIPP facility.

4. It is not the intent of this author to discuss the data or present a detailed data analysis in this report. The data is to be presented by others that are responsible for the thermal and structural studies for inclusion in a later report.

Gage and Measurement Considerations

5. In order to adequately describe the state of stress and deformation in a borehole seal, it is necessary to make measurements in a carefully

controlled model to obtain pertinent information on the actual state of stress and deformation. These measurements are important due to the complex state of stress and strain of largely unknown magnitude and distribution caused by large shrinkage or expansive stresses, temperature stresses, creep, etc.

6. Ideally it is desirable to place in a scale model a measuring device or gage small enough so as not to significantly disturb the stress field, yet large enough to give a meaningful average reading within the heterogeneous material. It is also desirable for the device to have sufficient sensitivity and accuracy to yield quantitative information about stresses and strains at particular locations in the model.

7. Geymeyer (1968) stated that "The ideal meter would perfectly match the viscoelastic and thermal properties of concrete, be completely waterproof, be insensitive to (or easily corrected for) temperature changes, have zero cross sensitivity and drift, have a resolution of a few units of microstrain and a total range of several thousand microstrain, be reliable, be noncorroding in the environment in which it is used, be easy to place and read, be inexpensive, and come in various sizes." Of course, there are no meters that meet all of these requirements, therefore, the measurement system designer's objective is to select meters that introduce minimal errors in the measurements by the imperfect matching of physical properties.

8. As pointed out by Geymeyer, some of the most significant mismatches of properties between the meter or gage and the surrounding material are differences in the elastic modulus, Poisson's ratio, and thermal expansion. He discusses these in detail in the referenced report and, therefore, these differences will not be discussed here. These differences were taken into consideration in the gage selection process.

9. One special consideration for an embedment strain meter is meter length. Since concrete is a heterogeneous material having extreme variation in local strains and stresses, it is generally agreed that the strain meter length should be at least two to three times the nominal maximum aggregate dimension. Some investigators have even suggested as high as five times.

PART II: LABORATORY PHASE

Test Plan

10. The laboratory phase test plan was designed to: (a) evaluate various embedment gages under consideration for field use; (b) develop a method of installation and monitoring for in situ tests; (c) simulate in situ test configurations with gages cast in an expansive concrete plug; and (d) collect data on the expansive characteristics of a salt-saturated concrete plug to support predictive model development.

Gage Selection and Description

11. A literature search was made to determine the kinds of gages that had been used in concrete structures with a relatively good degree of success or appeared to offer some desirable characteristic. The Carlson meters, Ailtech gages, and thermocouples have received extensive use for embedment in concrete structures. In fact, the Carlson meters have been used in hydraulic dams since the early 1950's. Vibrating wire gages, LVDT gages, SR4 resistance-wire strain gages, and others, were also considered.

12. Some of the candidate gages were removed from consideration for various reasons such as size, range, stability, accuracy, signal conditioning requirements, etc. The Carlson meters, Ailtech gages, and thermocouples were selected because of their extensive use in concrete structures by WES and others. The Sandia pressure cell was selected because of its small size and cost.

13. Carlson elastic wire meters. Carlson strain meters and stress meters (Carlson 1979) use an elastic-wire electrical resistance device as the sensing element. The device consists of two coils of fine steel wire wound on ceramic spools one of which increases in length and resistance with strain while the other decreases. The change in resistance is due mainly to stress; however, the measurement is strain.

14. The ratio of resistance of the two coils is directly proportional to change in gage length (strain). The total resistance of the two coils is directly related to temperature. A 1% increase in the length results in a 3.6% increase in electrical resistance. Both the ratio and the resistance can

be measured accurately with a Wheatstone bridge testing set to 0.01 percent and 0.01 ohms, respectively.

- a. Miniature strain meter. A Carlson Miniature Strain Meter was selected as one of the strain measuring devices to be used in the laboratory experiment. The model M-4 meter is 4.062 in. long and 0.63 in. in diameter. The range of the meter is 3900 micro-strains and has a least reading for strain of 5.8 micro-strains and for temperature of 0.1 deg. F.

The thermal coefficient of thermal expansion of the all steel meter frame is 6.7 micro-strains per degree F and, therefore, the temperature correction for the meter is this value. The meter is, however, almost self temperature compensating when embedded in concrete. For example the miniature strain meter would indicate no change in resistance ratio when concrete expands freely if the thermal expansion of concrete is 6.6 micro-strains per deg. F.

- b. Joint meter. The Carlson Joint Meter is similar to the strain meter except that the range is greater. This greater range is accomplished by having a coil spring in series with each of the two loops of elastic wire. It measures temperature and expansion or contraction in the same way as the strain meter.

The model JO.1 joint meter is approximately 10.25 in. long and 1.0 in. in diameter. The range of the meter is 0.02 in. contraction and 0.08 in. expansion. It has a least reading of 0.0002 in. for length change and 0.1 deg. F temperature.

The joint meter has a bellows near the center of the length that permits movement to be transmitted to the interior elastic wires. Thin plastic is formed over the bellows to prevent bonding or jamming by concrete or mud. A steel socket is available for embedding on one side of the joint. The joint meter is designed to screw into the socket such that approximately one-half the gage and bellows protrudes into the fresh concrete.

- c. Stress meter for concrete. The Carlson Concrete Stress Meter is a 7-in. diameter plate with a strain-meter sensing element mounted on one face. The plate has a mercury film at its mid-thickness and a flexible rim so that any stress through the plate is applied to the mercury film. Extraneous deformations due to causes other than stress, such as those due to drying shrinkage, have little effect on stress through the plate and the mercury. The calibration, therefore, is in terms of compressive stress per 0.01 percent reduction in the resistance ratio of the sensing element. To prevent the concrete from pressing against the sensing element and causing errors, a PVC plastic tube is attached to the main diaphragm in such a way that it surrounds the sensing element but does not touch it, therefore, isolating it from the concrete.

The model CS70 stress meter was used in preference to other models because the CS70 combines the most favorable design

characteristics. The C800 has a range of 800 psi with a least reading of stress of 3 psi and temperature of 0.1 deg. F.

15. Ailtech CG/20 series embedment strain gage. The Ailtech Embedment Strain Gage (Eaton Corp. Manual) is a 120-ohm, quarter bridge, self-temperature compensating strain gage that is designed for embedment in concrete or like material and for measurement of internal tensile and compressive strains over a temperature range of 0° to 180° F. The hermetically sealed, integral lead wire strain gage consists of a resistance nickel-chrome (NiCr) wire insulated by compacted MgO powder in a 0.040-in. diameter stainless steel tube. Perforated metal discs are attached to the steel tube at extreme ends for the purpose of alignment and placement.

16. The gages are available in 2-in., 4-in., and 6-in. lengths. The average modulus of elasticity for the gages is approximately 9.5×10^6 psi, which is significantly larger than that usually associated with normal concrete. For minimum error gage lengths should be approximately 4 times the nominal maximum aggregate size.

17. The Ailtech gage is self-compensated for concrete with a thermal coefficient of expansion of 6.0 micro-strains per °F. It is equipped with three leads and must be wired to the bridge circuit like a normal three-wire strain gage hookup. Since concrete exhibits a change in modulus during curing, the measured strain data are useful for trends, not specific data, until the concrete has gained 25-50% of its final strength (Eaton Corp. Manual). After that, the gage output is a true representation of the growth, contraction, or mechanical strain within the material.

18. Sandia pressure gage. The Sandia pressure gage is constructed of corrosion-resistant Inconel 600. It is disc shaped, 1.5 in. in diameter, and 0.30 in. thick. Sandwiched between a ring clamp and transducer body is a 0.02-in. thick diaphragm with a self-temperature-compensating four-arm active strain gage bridge bonded to it. The bridge unbalance resulting from diaphragm deformation is equated to an external pressure on the gage by means of a fluid calibration. The range of the gage is 0-1,000 psi, with a maximum allowable temperature of 212° F. The resolution of the measurement is ± 0.1 psi.

19. The physical size and corrosive resistance of the SNL pressure gage made it attractive for use in these experiments. The gage had received

extensive use in other experiments at the WIPP primarily in small diameter satellite instrumentation holes in rock wall.

20. Type T and Type E thermocouples. Type T Thermocouples made at WES from thermocouple wire was used in the laboratory experiment. The copper-constantan (type T) thermocouple has a useful range of -200 to 350 deg. C, has an average sensitivity of 40.5 micro volt per deg. C, and is considered to be good for use where moisture is present. The thermocouples were not encased for this experiment. Type T thermocouples are commonly used in concrete.

21. The thermocouples selected for field use were Type E, Chromel-Constantan, thermocouples that are commonly used by Sandia National Laboratories in field experiments. The useful range is -200 to 900 deg. C and has an average sensitivity of 67.9 micro volt per deg. C. The thermocouples were encased and nongrounded to shield.

22. SR-4 strain gages. An electrical resistance strain gage is another device used to measure strain. The gage, bonded or attached to a body, is so constructed that any strain occurring in the body after the gage adhesive cures is accompanied by a proportional change in electrical resistance of the gage. These gages are generally referred to as SR-4 strain gages.

23. Some advantages of the SR-4 strain gage are: (1) very small in size and mass; (2) simple to install; (3) high sensitivity to strain; (4) inexpensive; (5) usable for both static and dynamic strains; (6) easily monitored remotely; and (7) only slight sensitivity to ambient variables. The main disadvantage is the drift which occurs over a long period of time. With regard to its sensitivity to ambient variables, the gage can usually be protected or compensated for variables.

24. The SR-4 strain gages were selected for bonding to both the internal and external surfaces of the 9-in. diameter pipe used in the laboratory and to the rock wall in the field test. Both vertical and circumferential gages were used and monitored independently in a four-arm bridge configuration with a dummy temperature-compensating gage (for the laboratory experiment only) placed in the adjacent arm.

25. The gage element for the SR-4 gage is constantan foil with a tough, flexible, polyimide backing. The strain range for this gage is 75 percent. ($\pm 50,000$ millinths). However, due to the nonlinear relationship between the output voltage and strain in a Wheatstone-bridge circuit, the strain range

should be considered $\pm 1,000$ millionths. The resolution in the measuring circuit is approximately 10 millionths.

Accuracy of Measurements

26. In addition to errors associated with the electronic recording system, errors from various other sources enter into measurements with embedded instruments some of which are the responsibility of the manufacturer and others the responsibility of the user. Each type of instrument has some unique errors associated with it and other errors that are common to most embedded instruments. It is important that the sum total of all errors be small if useful results are obtained.

- a. Carlson meters (Carlson, Accuracy of ...). A calibration constant is supplied with each Carlson meter implying that the relationship between change in length and resistance ratio is linear. However, this is not exactly the case. A small part of the wire does not participate in the length change. The manufacturer keeps the error associated with this cause well below 2 percent.

A meter or gage embedded in a continuous medium such as concrete is not identical to the material around it, thus, creating a local disturbance of strains. The strains being measured are, therefore, different from what would have occurred if the meter was not embedded. The meter acts like a cavity in an already strained mass of concrete because its longitudinal modulus of elasticity is almost negligible compared with that of concrete. The concrete tends to deform slightly into this cavity. The deformation of the meter from this cause is due to stress and can be as large as 8 percent. By making the strain meters with the flange screw recessed and with a soft pad at either end of the meter so that anchorage is only at the outer edge of each end flange, the manufacturer has reduced the deformation due to the "void effect" to only about one third or a maximum of about 3 percent.

- b. Ailtech embedment strain gage. The gages are available in 2-in., 4-in., and 6-in. lengths. The average modulus of elasticity for the gages is approximately 9.5×10^6 psi, or about three times that usually associated with normal concrete. It has been shown by Y.C. Loh (Loh 1951) that for a given ratio of gage modulus to concrete modulus (E_g/E_c), the strain increment factor (C_e) or error introduced in internal measurement by imperfect matching of the physical properties of concrete and gage, decreases as the length to radius (L/R) increases. Therefore, for an embedded strain gage, it is desirable to keep L/R as large as practical. According to Loh, the relation between indicated strain E_g and actual strain E_c can be expressed by the following equation:

$$E_g = E_c (1 + C_e).$$

Loh presented a graph of strain increment factor versus ratio of gage modulus for various L/R values. From this graph it can be determined that for a 2-in. Ailtech Embedment Strain Gage having an E_g/E_c value of 3 and an L/R value of approximately 100, the gage should indicate elastic strains only slightly lower than the actual elastic strain in the concrete.

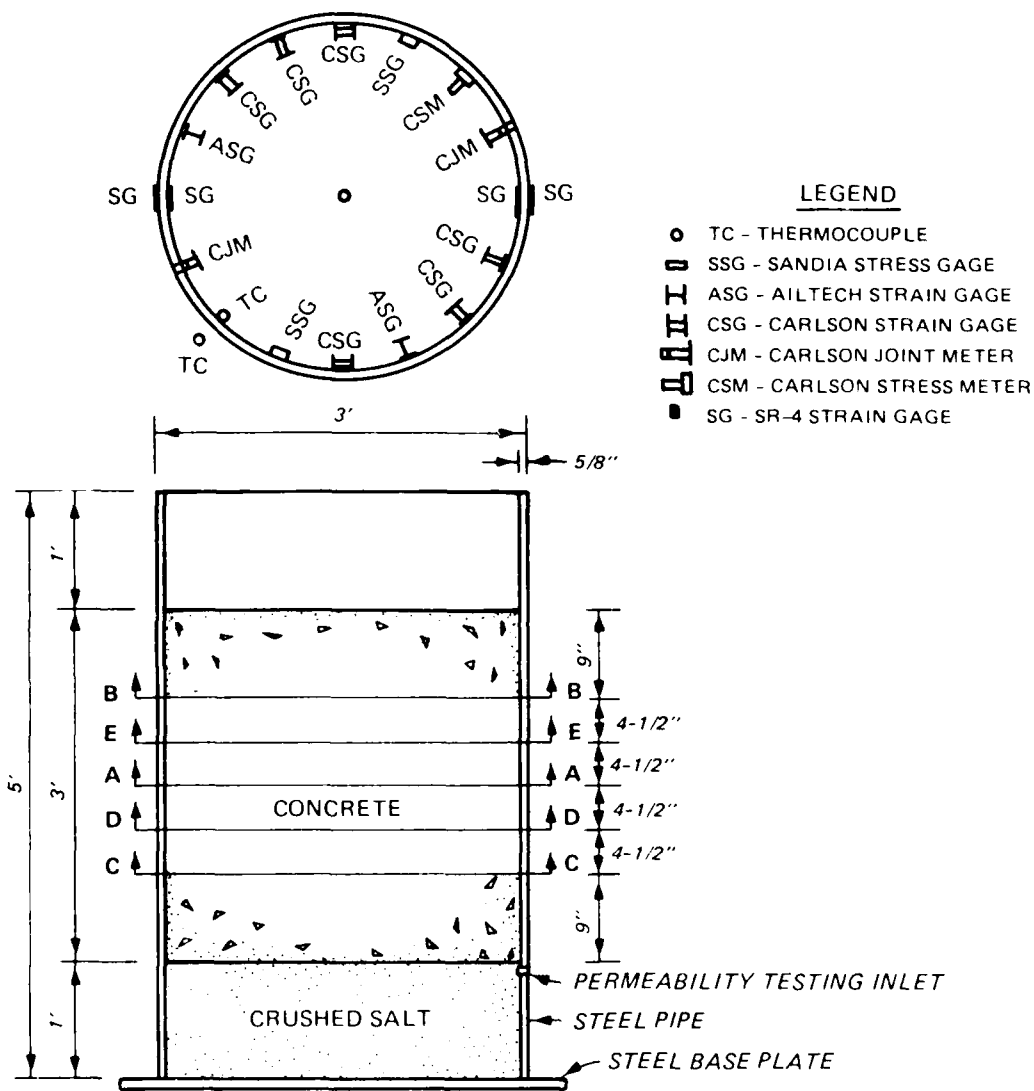
To minimize strain errors, the ratio of gage length/nominal maximum aggregate size should be greater than 4. A graph showing percentage error which can be expected versus gage length/nominal aggregate size ratio is provided in the Ailtech Operation and Maintenance Manual (Eaton Corp., Manual). A gage having a length of 2 in. was selected for this experiment because of the relative small size of the concrete plug. However, the nominal maximum aggregate size for the proposed concrete plug was 3/4-in. giving gage length/nominal aggregate size ratio of 2.67. This ratio could produce an associated error of approximately 10 percent for all strain measurements obtained with the 2-in. Ailtech strain gage in this concrete mixture.

- c. SNL pressure gage. The SNL Pressure Gage sensing element is a thin Inconel 600 diaphragm with bonded strain gages connected in a 4-arm bridge that is compensated against the effect of wide ambient temperature variations. The gage is highly linear, exhibits very low hysteresis and excellent repeatability. The resolution of the measurement is ± 0.1 psi.
- d. Thermocouples. The limits of error for the type T thermocouple over the temperature range of 0 to 350 deg. C is $\pm 1.0^\circ\text{C}$ or $\pm 0.75\%$ whichever is greater. The limits of error for the type E over the temperature of 0 to 900 deg. C is ± 1.7 deg. C or $\pm 0.5\%$ whichever is greater. These errors do not include application or installation errors.

Laboratory Experiment

27. The laboratory experiment was conducted at the WES Structures Laboratory, Concrete Technology Division, Vicksburg, Mississippi. The experiment was designed to simulate field conditions as much as practical using the gages previously selected as candidate gages for the field test.

28. Test configuration. The test was to consist of casting an expansive concrete plug, 3 ft in dia. by 3 ft long, in a 34-3/4-in. I.D. by 5-ft long steel casing with 5/8-in. wall thickness and measuring the stresses and strains in the concrete plug with numerous internal and external gages. A cross section of the experiment is shown in Figure 1. It shows the 5-ft long,



36-in. diameter pipe with a steel base plate, 12 in. of crushed salt and 36-in. expansive concrete plug. It also shows the levels at which electronic gages were located. Figures 2 and 2A show the layout of gages at each level and their primary direction of measurement.

29. Prior to embedment, stress, strain, and temperature gages were assembled on a mounting support tree or jig. Figure 3 is a photograph showing the support tree with the internal gages, with the exception of Carlson Stress and Joint Meters and SR4 strain gages, mounted on the tree. Figure 4 is a photograph showing the support tree and gages in place in the steel casing. SR-4 strain gages were placed both on the inside and outside of the pipe at the locations as indicated on Figure 2. The two Carlson Stress Meters were attached to the side walls of pipe using an epoxy-resin adhesive and the two Carlson Joint Meters were threaded into threaded holes in the side walls of the pipe.

30. Conduct of test. At 9:15 AM on 25 April 1985, the salt-saturated concrete was placed in the pipe using a tremie pipe and funnel in order to obtain maximum placement density and create as little disturbance as possible to the gages. Gages were observed for disturbance as the concrete was hand poured into the tremie pipe using 5-gal buckets (Figure 5). After a 3-ft-high plug had been emplaced, the concrete was vibrated using a small pencil-size internal vibrator. Caution was taken to only vibrate in predetermined areas in order to avoid vibrator contact with gages. The placement and vibration was completed at 11:12 AM, 25 April 1985. Additional information about the concrete used for this test is given by Wakeley and Poole (1986).

31. The gages were monitored with a Hewlett-Packard Model 3497A data acquisition system and a Hewlett-Packard Series 200 computer. Figure 6 is a photograph of the pipe and monitoring system. Some of the external SR-4 strain gages on the pipe with cables can be seen. The system was set up to take data every 30 min for the first 180 hr and then every 4 hr to the completion of testing at 8:17 AM, 20 June 1985.

32. Preliminary test results. All of the gages survived the placement and vibration of the concrete. Although data were gathered prior to and during concrete placement, the validity of early-age measurements is questionable because of induced stresses and strains from the forced movement of concrete. Data from time of completion of vibration, 11:12 AM, 25 April 1985, has been plotted with all strains and stresses set at zero amplitude at 11:12 AM. It

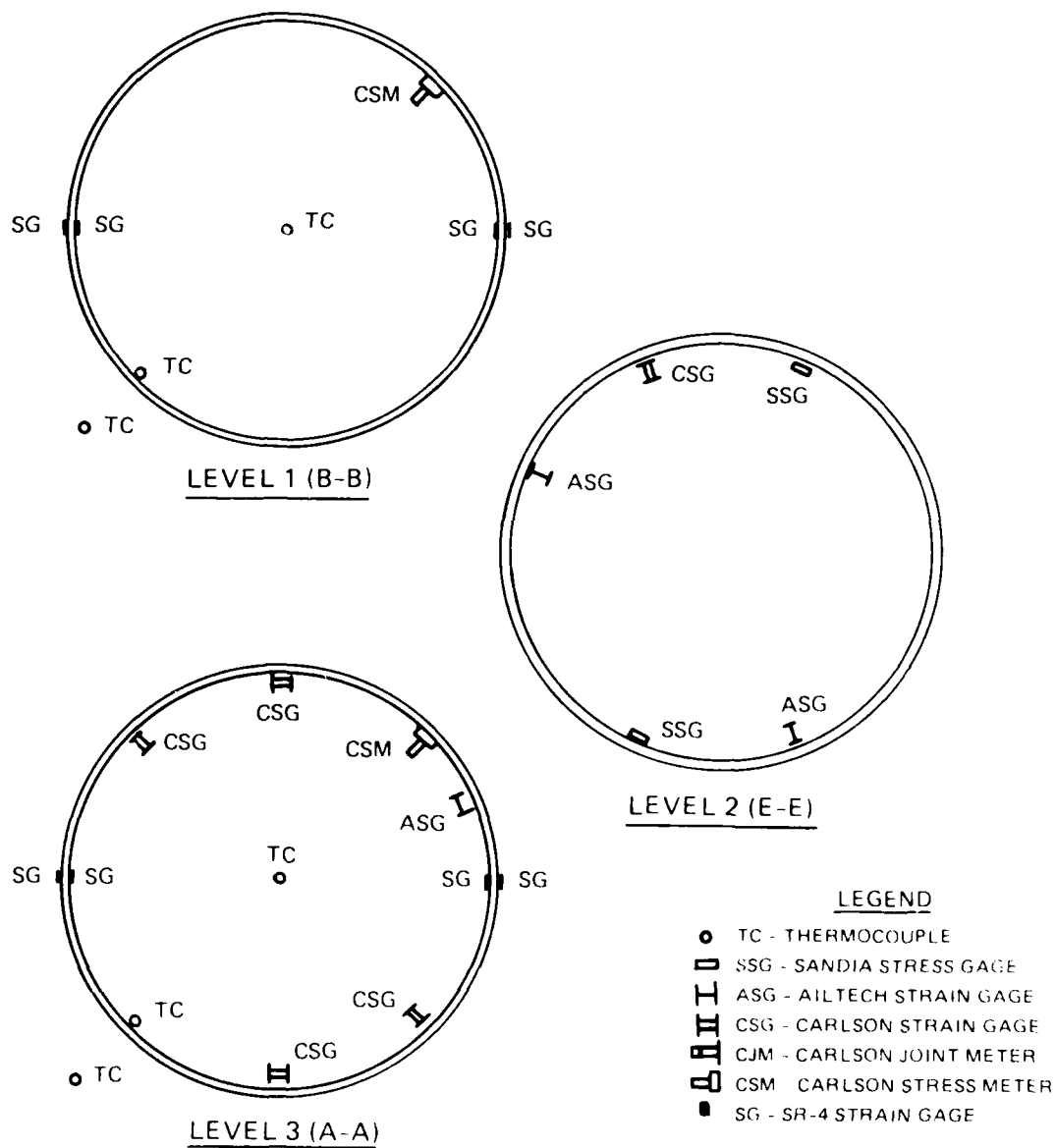


Figure 2. Position of gages in 36-in. diameter pipe test, level 1 (B-B), level 2 (E-E), and level 3 (A-A)

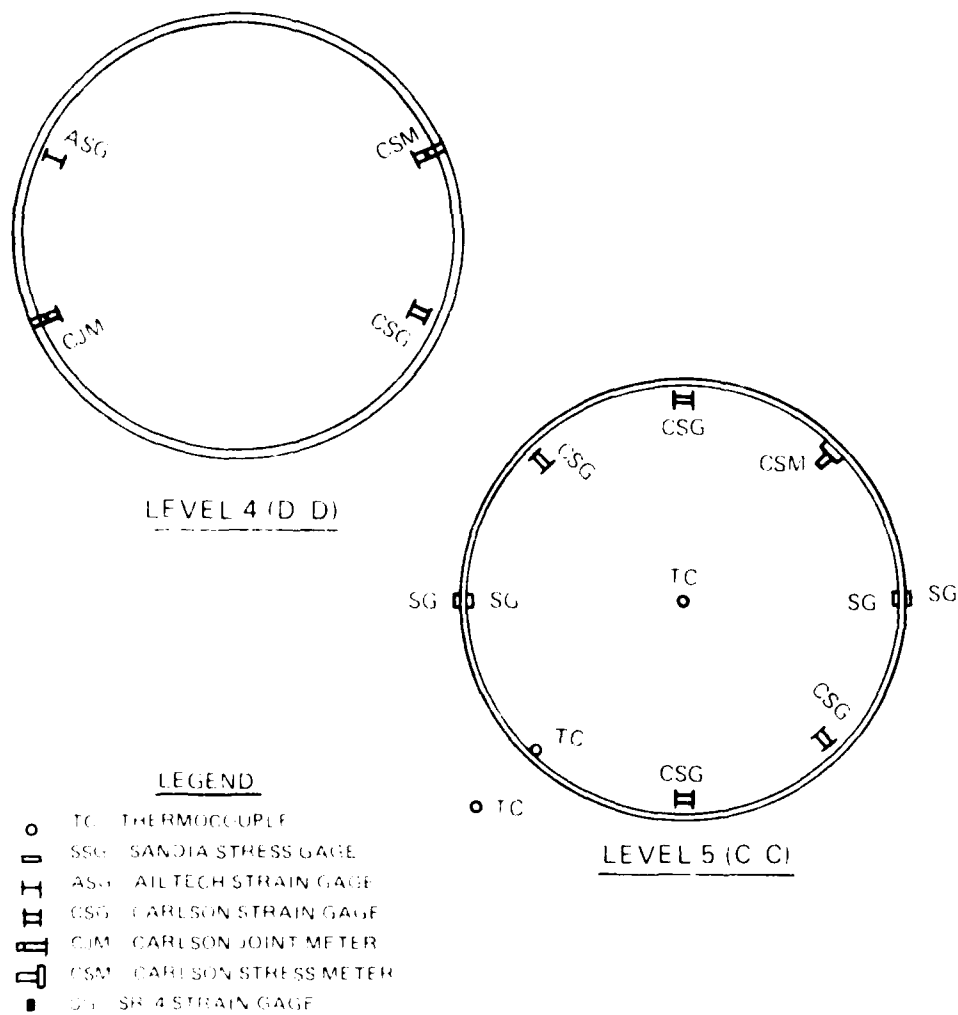


Figure 2A. Position of gages in 36-in. diameter pipe test, level 4 (D-D) and level 5 (C-C)

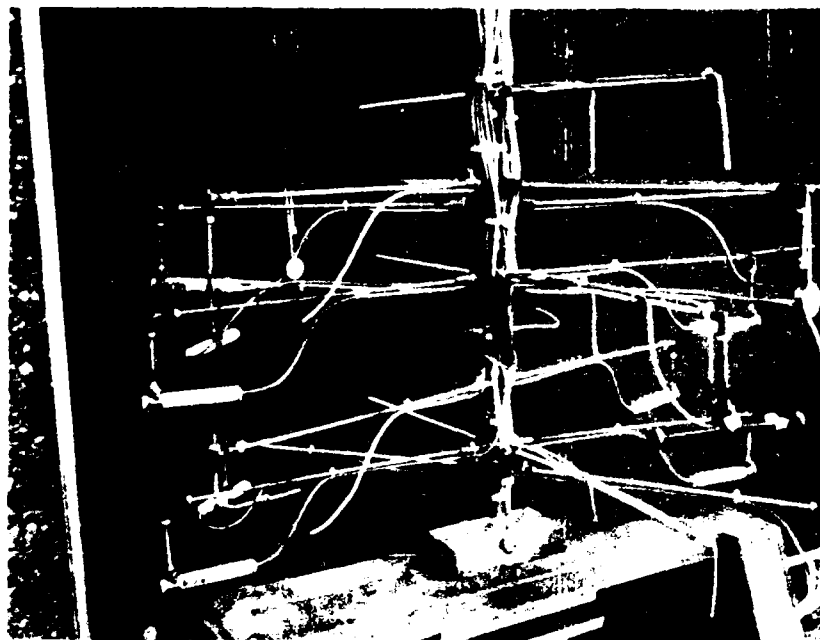


Figure 3. Assembly support tree with gages

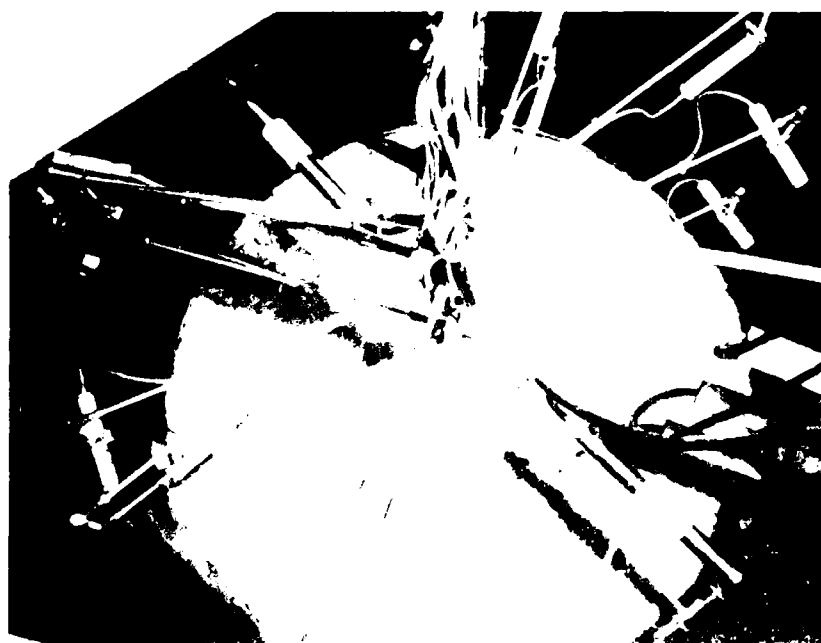


Figure 4. Cape assembly mounted inside the capsule



Figure 5. Placement of concrete



Figure 6. Monitoring equipment & experiment

should be kept in mind, however, that most embedded instruments or gages do not respond accurately until after the concrete has achieved a degree of rigidity.

33. As stated earlier in this report, it is not the intent to discuss the data or present a data analysis in this report. This will be discussed in another report by others. What is important is that data have been recorded for all gages except the SNL Pressure Gages. The SNL gage did not show any significant response. The probable cause is that air voids formed adjacent to the small recessed active diaphragm buffering the concrete and the gage. Figures 7-30 are example plots of the output from each type gage.

34. Since no useful data were obtained from the SNL pressure gages, additional SNL gages were placed in another experiment being conducted in which the same concrete was placed in a 19-in. diameter pipe. Extra care was taken to make sure that the concrete was vibrated adequately near the gages to try to prevent the formation of an air void adjacent to the active diaphragm. The gages in this experiment did measure significant pressures that appeared to be of a believable magnitude. Since this experiment was not designed to compare gages, no provisions were made to check the SNL gage response with other stress gages.

35. After reviewing the data from the laboratory experiment, it was decided to make use of all the gages in the field experiment. More emphasis was placed on the use of the Ailtech Strain Gage and SNL Pressure Gage in the field than that of the laboratory experiment.

CARLSON STRAIN GAGES

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE

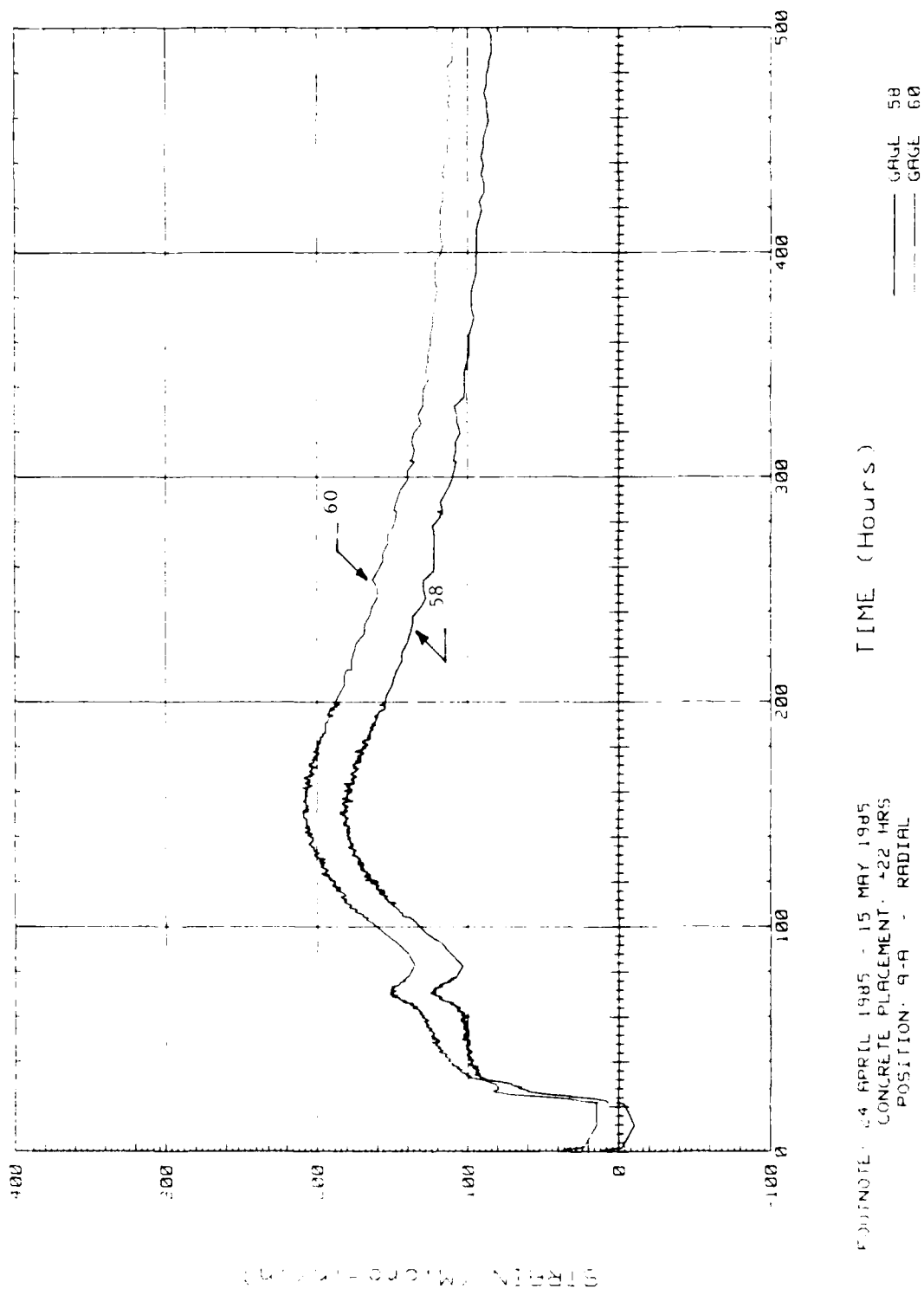
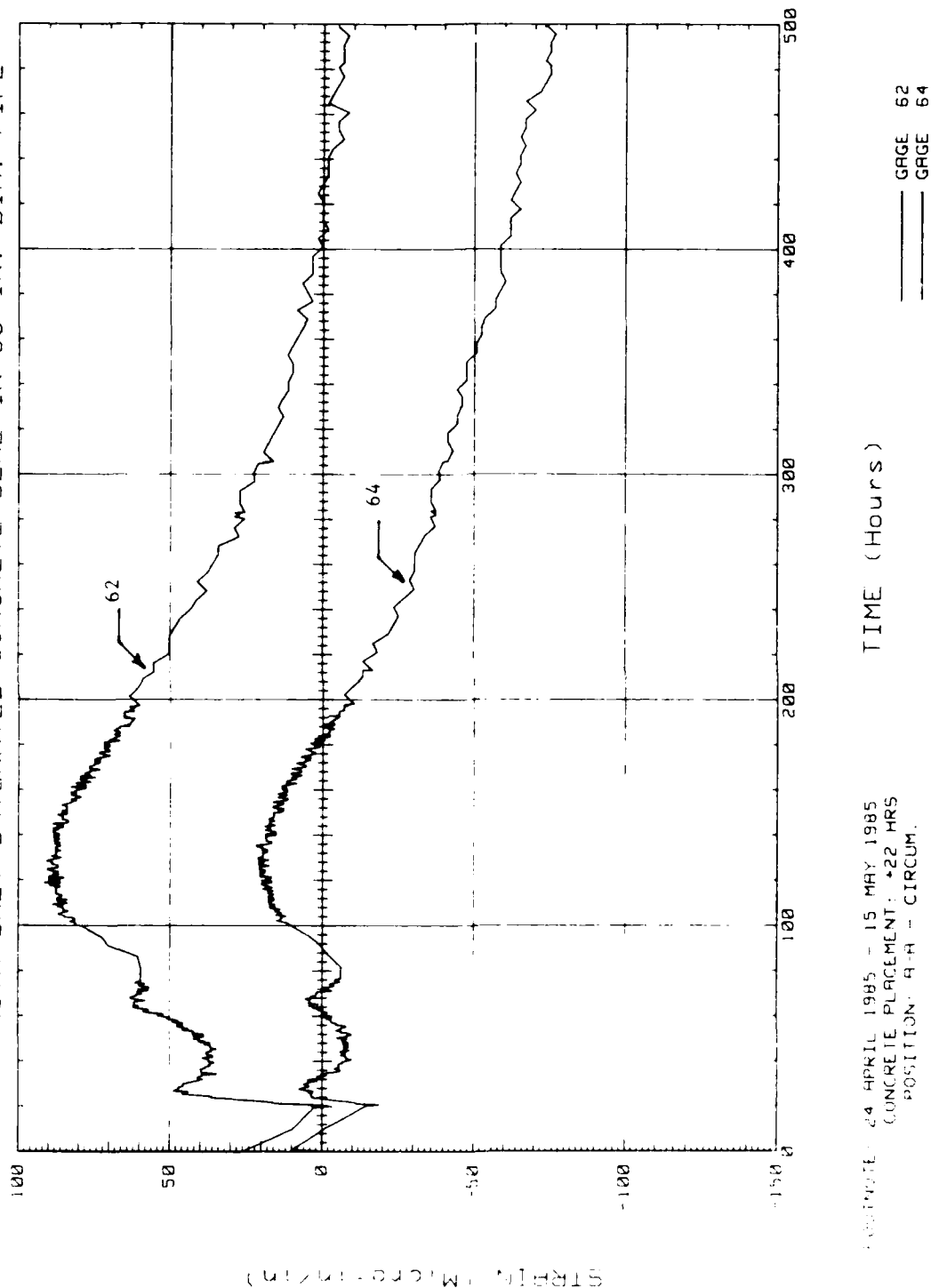


Figure 7. Carlson strain gages 58 and 60

CARLSON STRAIN GAGE

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE

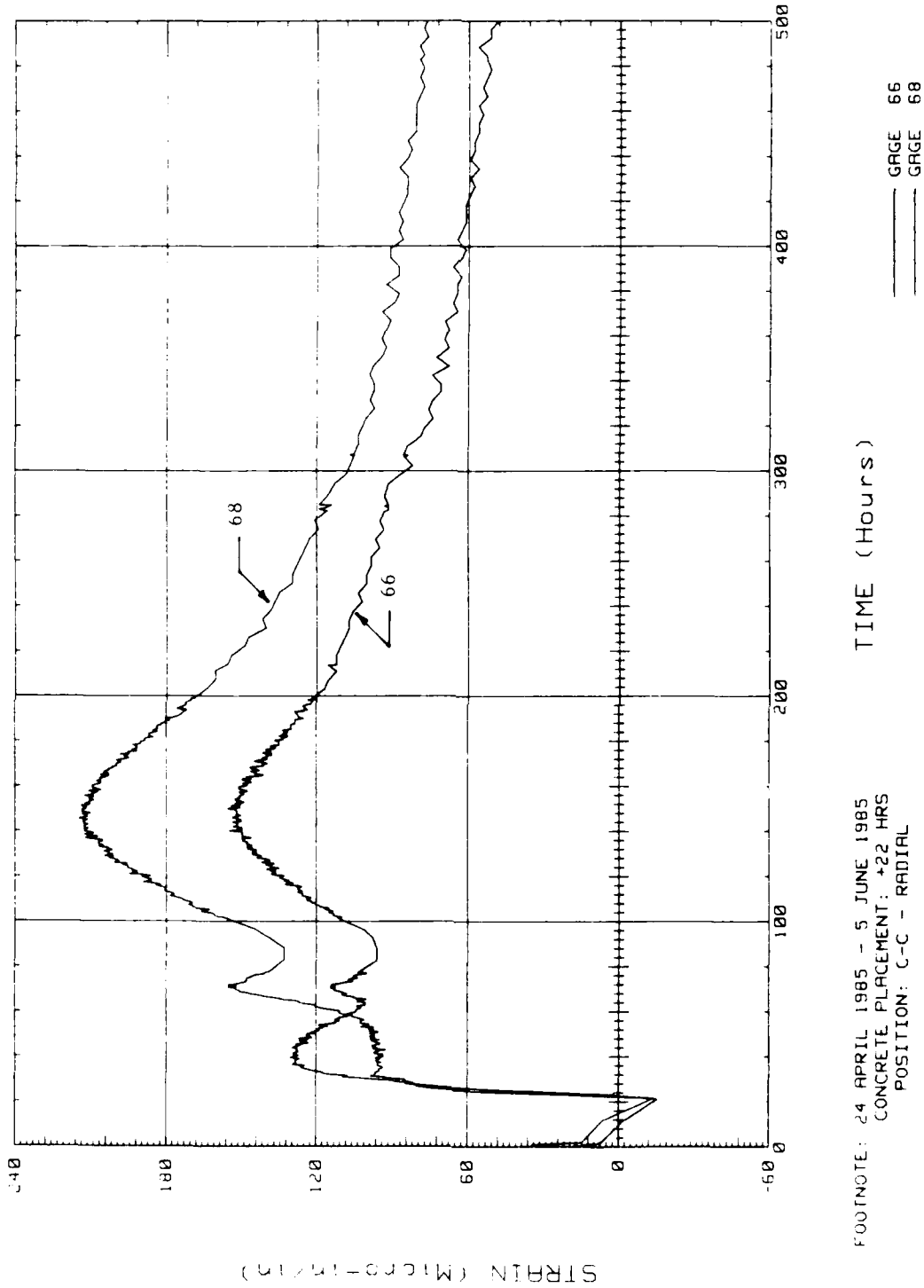


EXPERIMENT: 24 APRIL 1985 - 15 MAY 1985
CONCRETE PLACEMENT: +22 HRS
POSITION: 9-A - CIRCUM.

Figure 8. Carlson strain gages 62 and 64

CARLSON STRAIN GAGES

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE

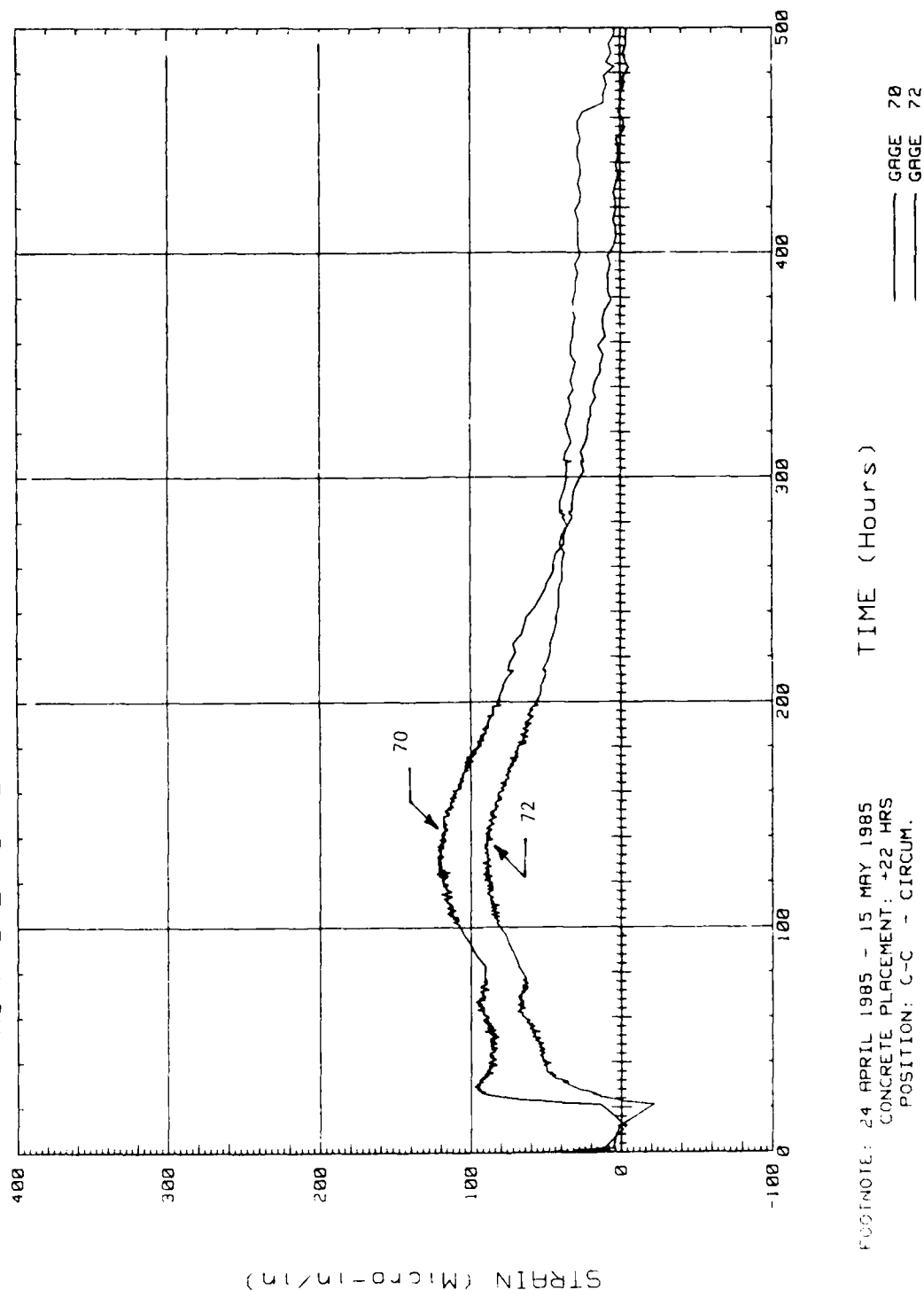


FOOTNOTE: 24 APRIL 1985 - 5 JUNE 1985
CONCRETE PLACEMENT: +22 HRS
POSITION: C-C - RADIAL

Figure 9. Carlson strain gages 66 and 68

CARLSON STRAIN GAGES

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE

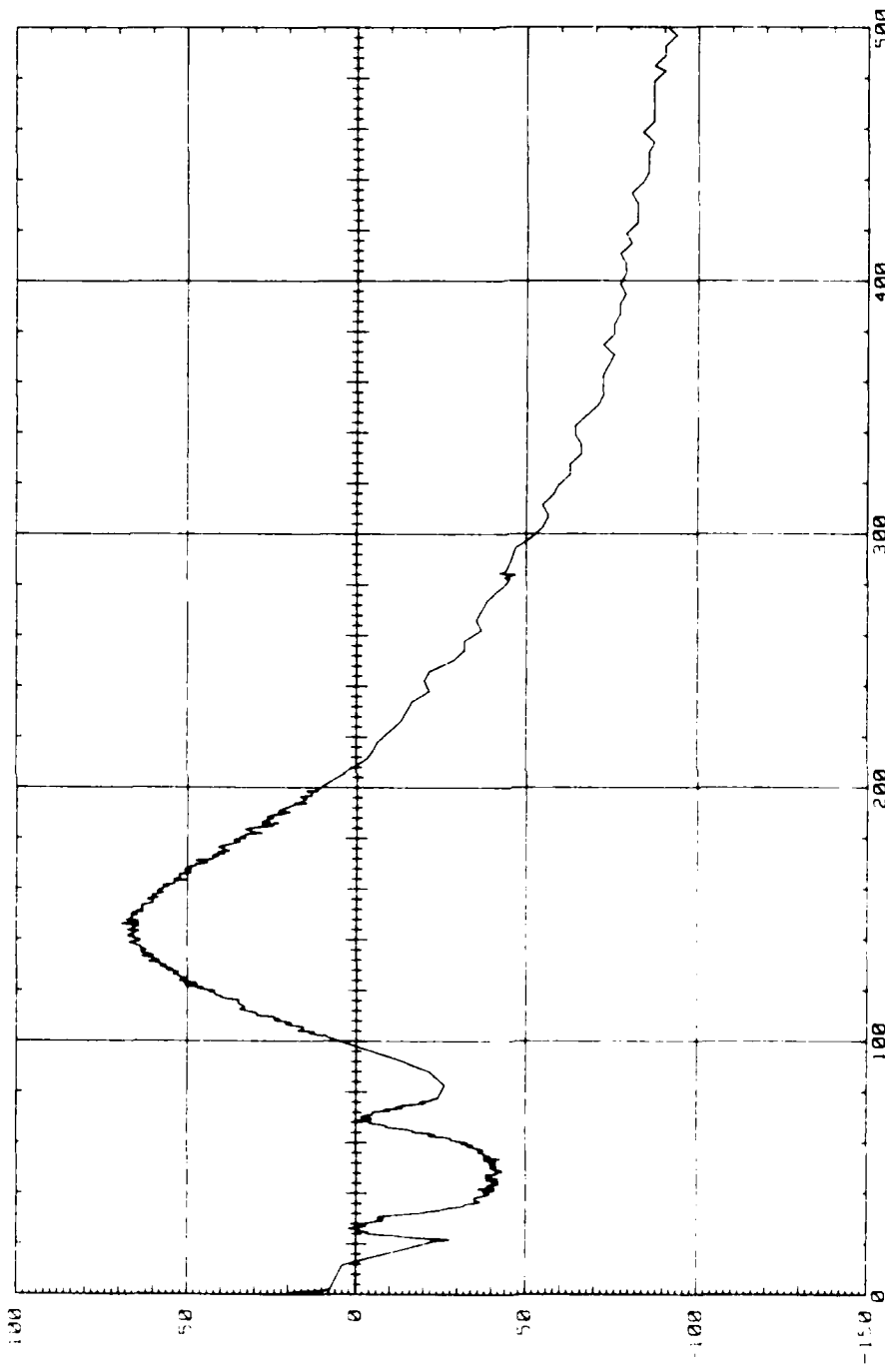


FOOTNOTE: 24 APRIL 1985 - 15 MAY 1985
CONCRETE PLACEMENT: +22 HRS
POSITION: C-C - CIRCUM.

Figure 10. Carlson strain gages 70 and 72

CARLSON STRAIN GAGE

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE



FOOTNOTE: 24 APRIL 1985 - 15 MAY 1985
CONCRETE PLACEMENT: +22 HRS
POSITION D-D - RADIAL

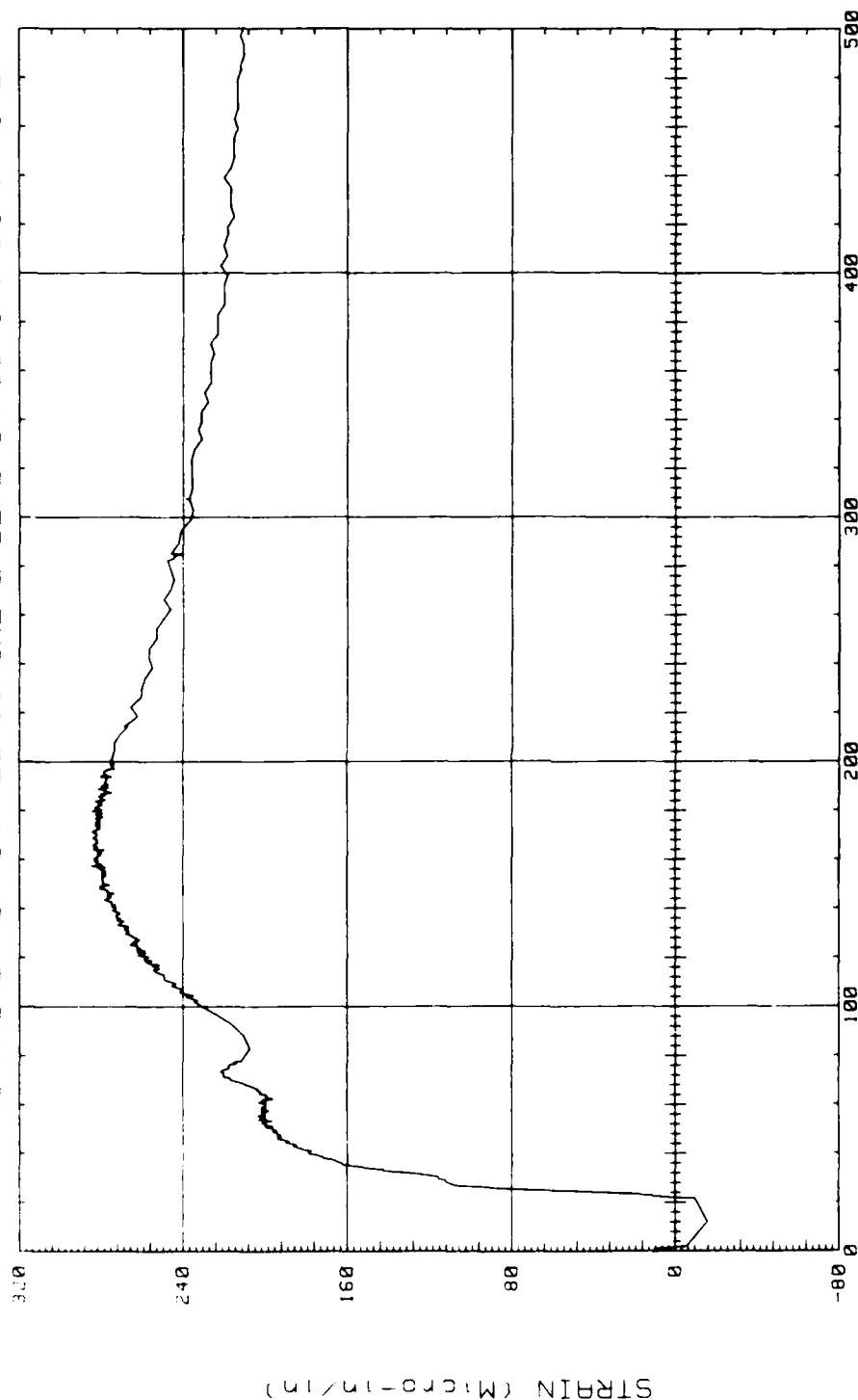
TIME (Hours)

— GAGE 74

Figure 11. Carlson strain gage 74

CARLSON STRAIN GAGE

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE



FOOTNOTE: 24 APRIL 1985 - 15 MAY 1985
CONCRETE PLACEMENT: +22 HRS
POSITION: E-E - RADIAL

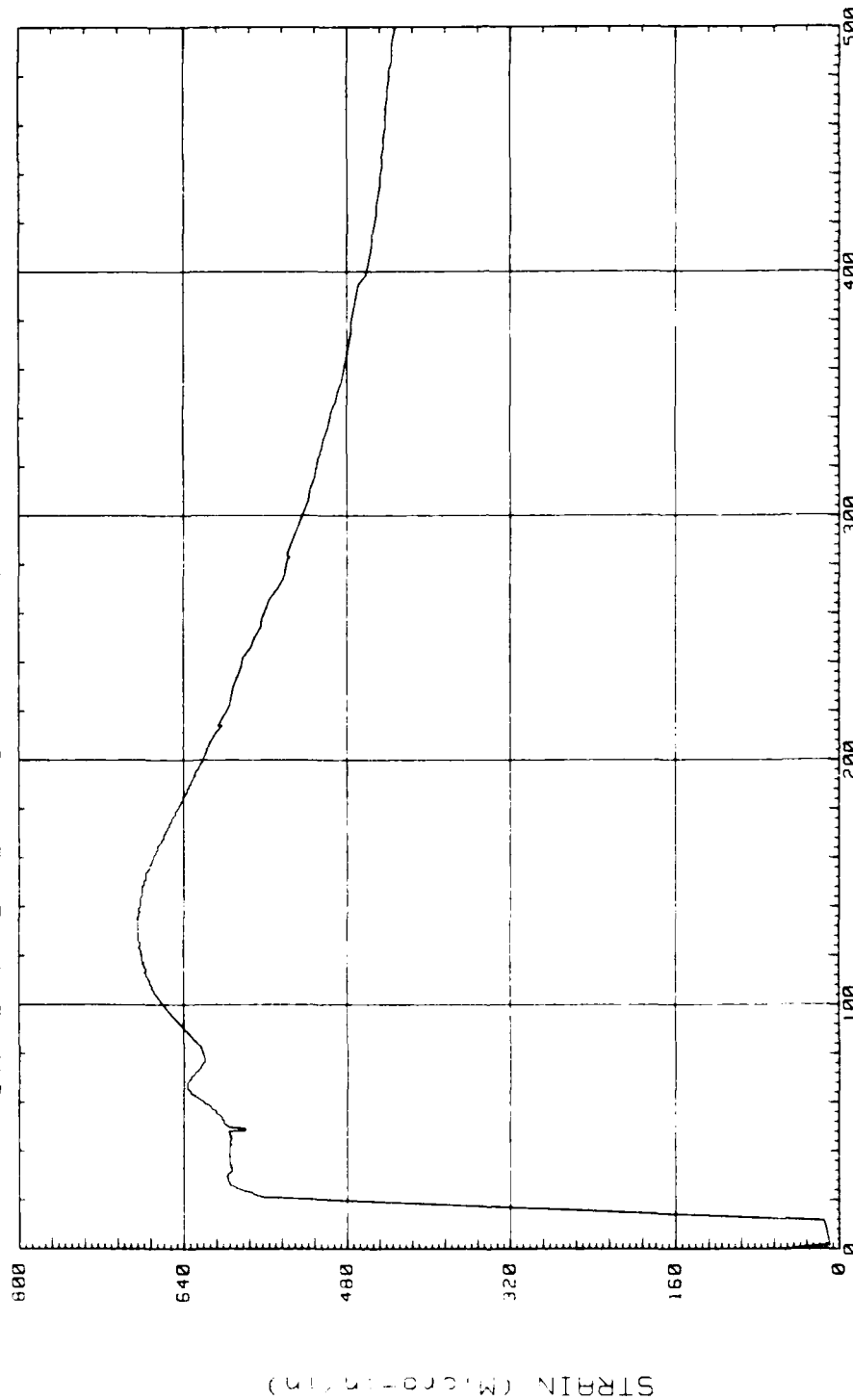
TIME (Hours)

— GAGE 76

Figure 12. Carlson strain gage 76

AILTECH STRAIN GAGE

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE



FOOTNOTE: 24 APRIL 1985 - 15 MAY 1985
CONCRETE PLACEMENT: +22 HRS
POSITION: A-A - CIRCUM.

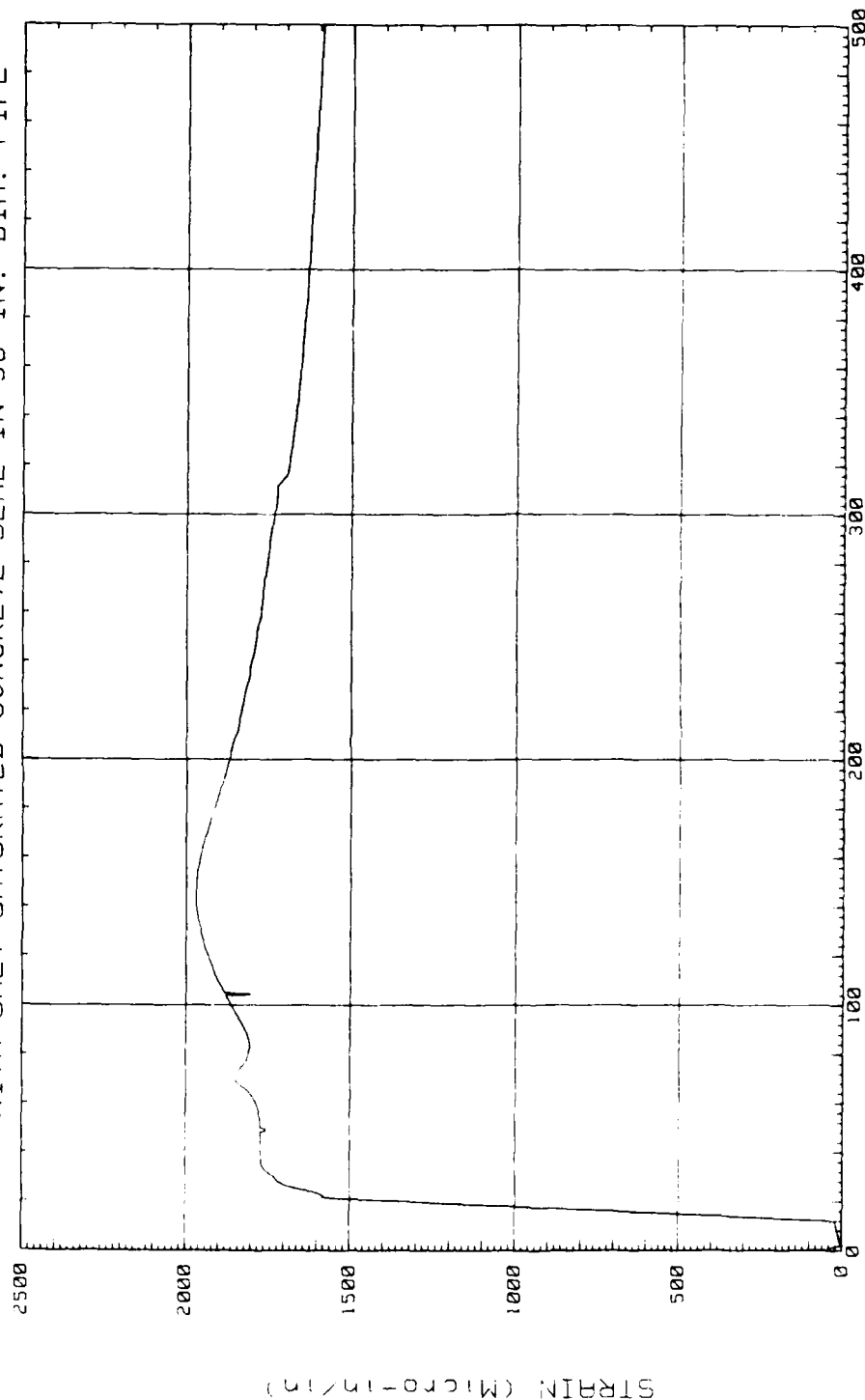
TIME (Hours)

— GAGE 53

Figure 13. Ailtech strain gage 53

AILTECH STRAIN GAGE

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE



FOOTNOTE: 24 APRIL 1985 - 15 MAY 1985
CONCRETE PLACEMENT: +22 HRS
POSITION: D-D - RADIAL

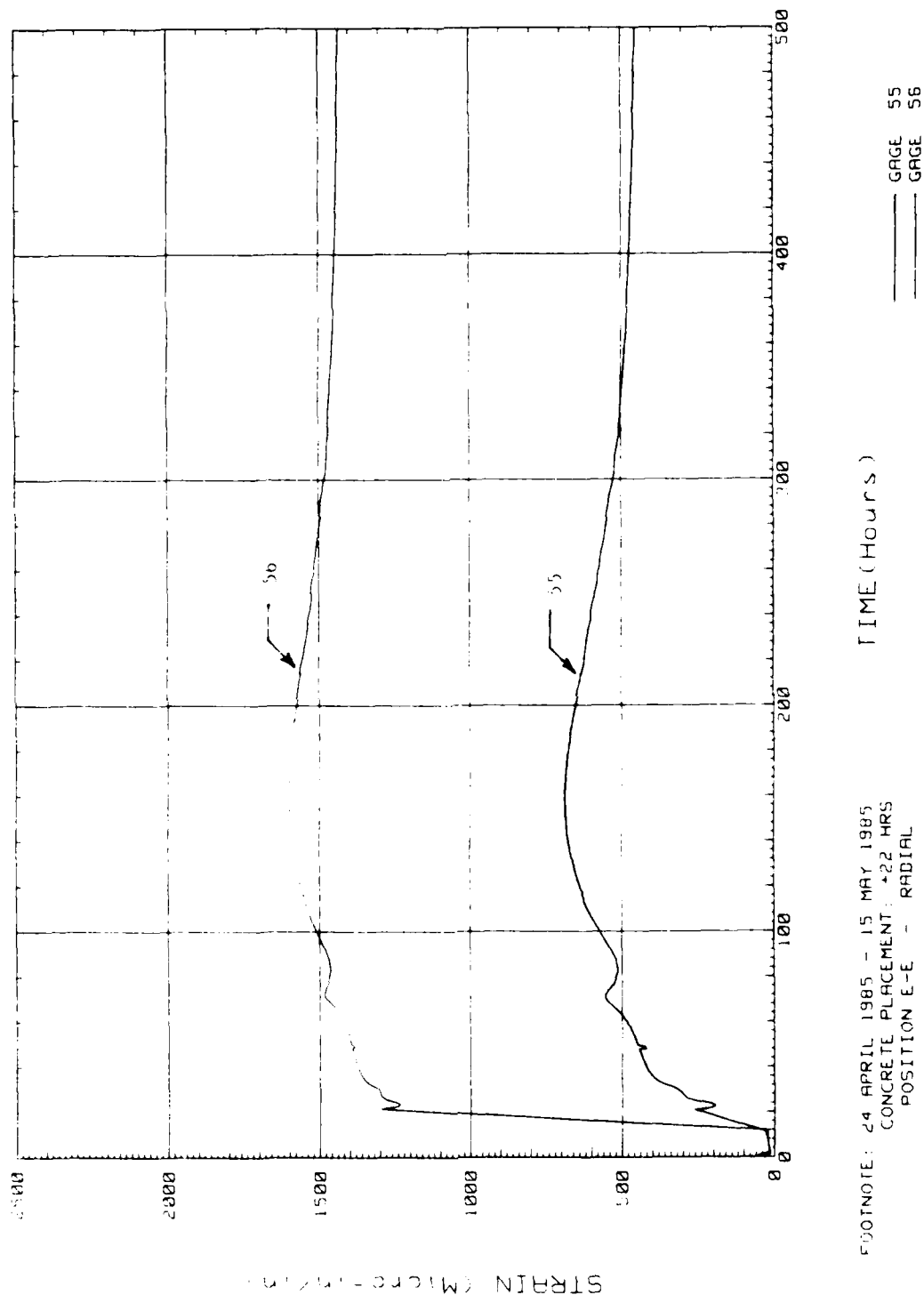
TIME (Hours)

— GAGE 54

Figure 14. Ailtech strain gage 54

AILTECH STRAIN GAGES

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE

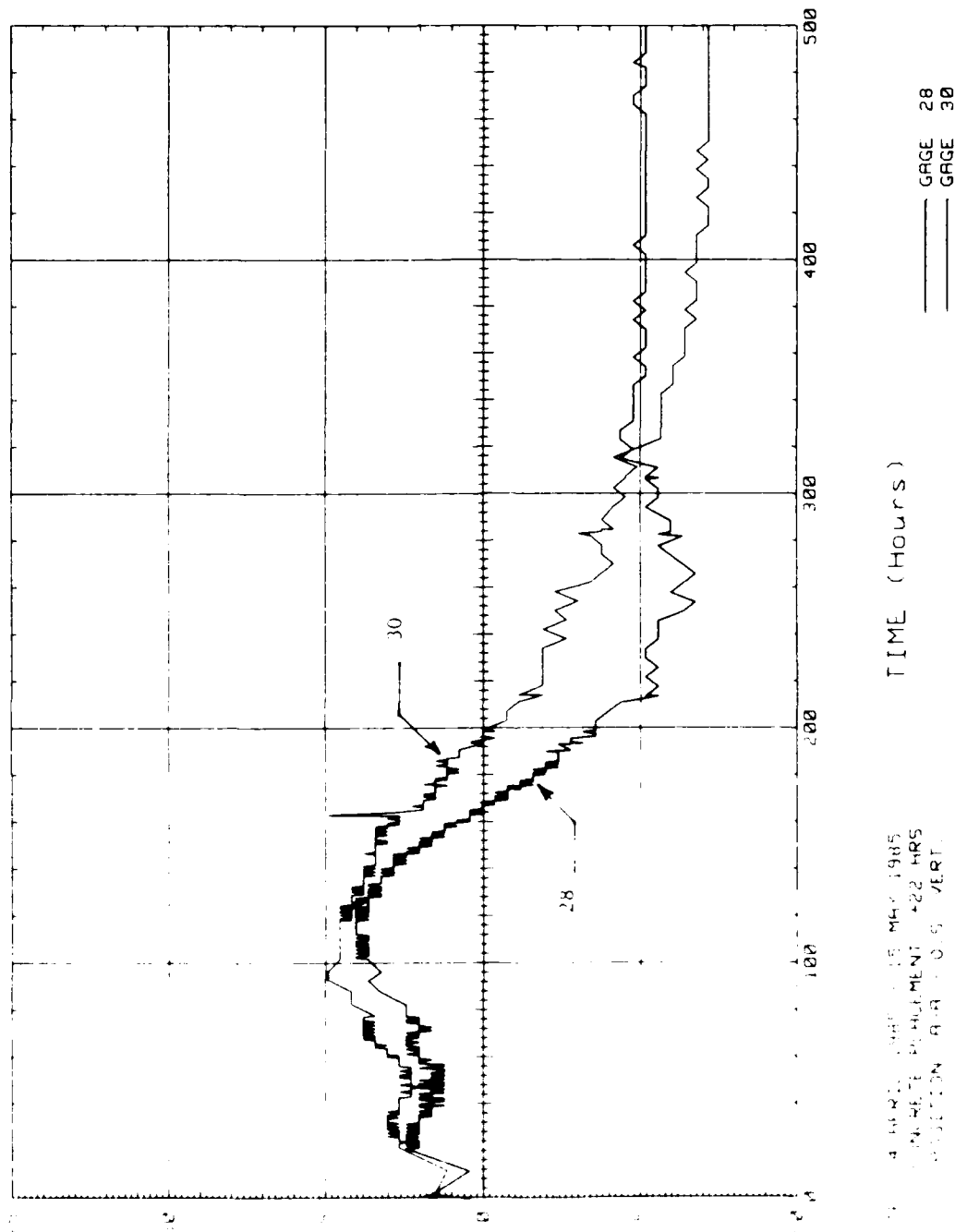


FOOTNOTE: 24 APRIL 1985 - 15 MAY 1985
CONCRETE PLACEMENT: 4:22 HRS
POSITION E-E - RADIAL

Figure 15. Ailtech strain gages 55 and 56

SR-4 TYPE STRAIN GAGES

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE



EXPERIMENTAL DATA
CONCRETE SEALING
POSITION 9A-10.5 VERT.

Figure 16. SR-4 type strain gages 28 and 30

SR-4 TYPE STRAIN GAGES

WIPP LABORATORY EXPERIMENT
 WITH CRP SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE

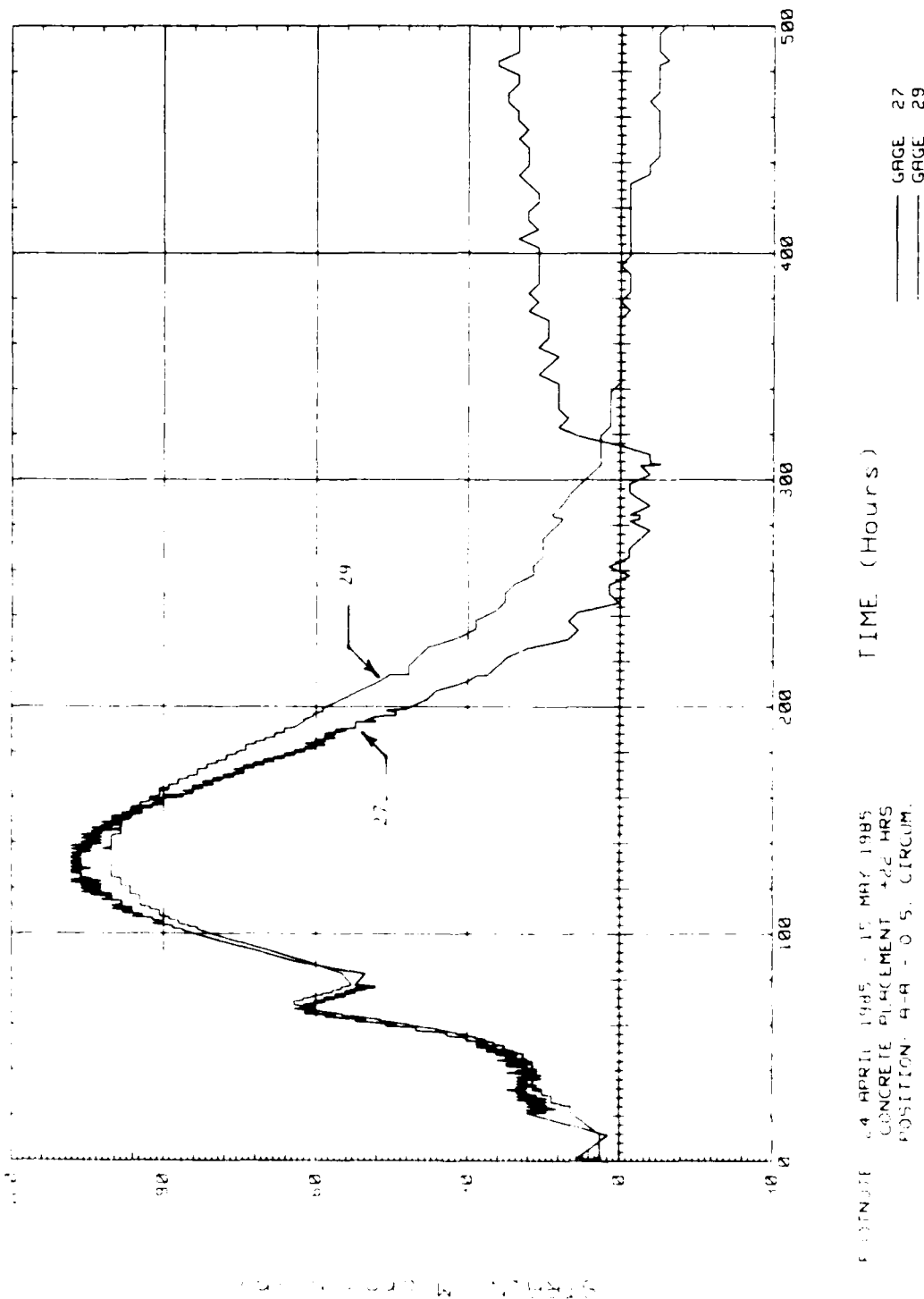


Figure 17. SR-4 type strain gages 27 and 29

SR-4 TYPE STRAIN GAGES

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE

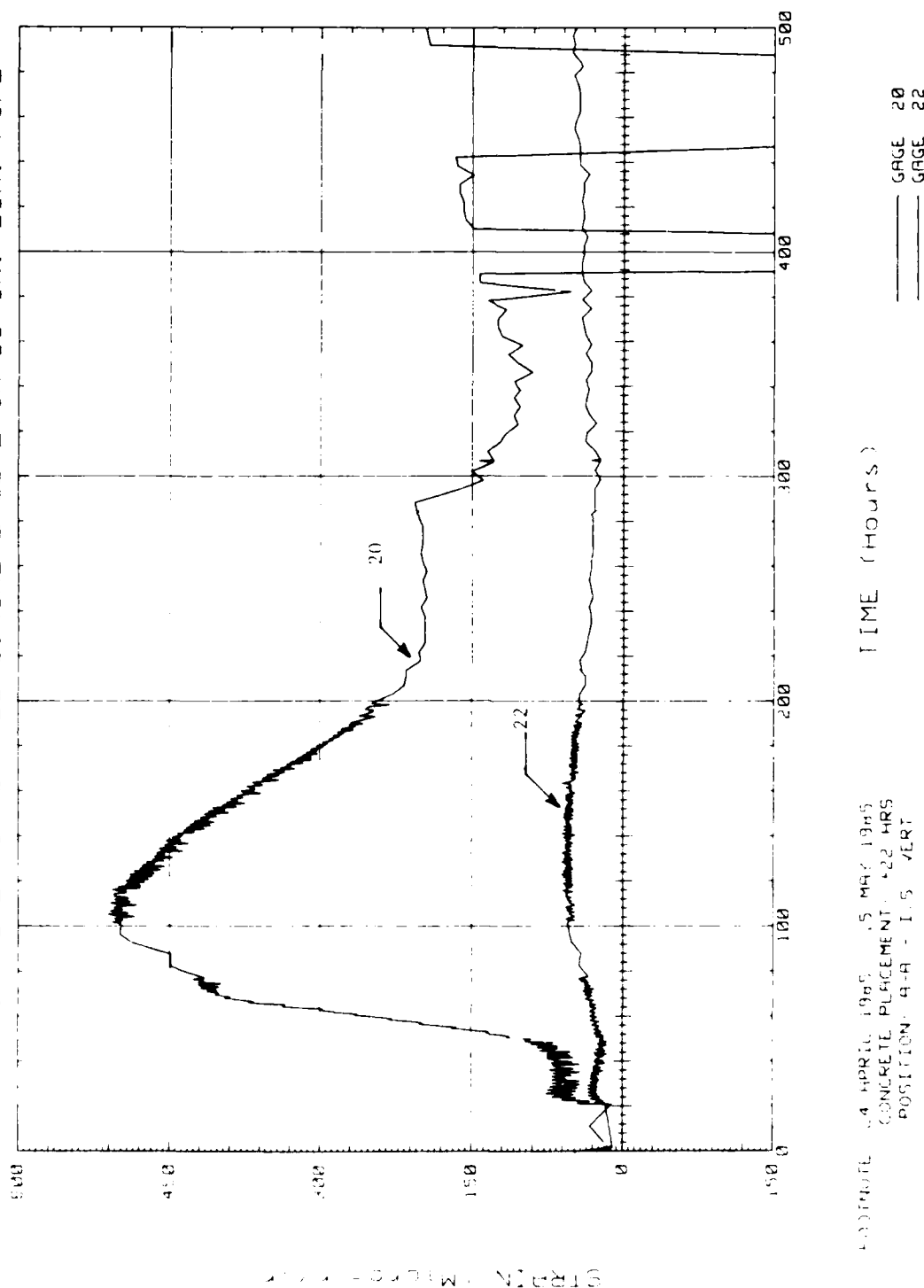


Figure 18. SR-4 type strain gages 20 and 22

SR-4 TYPE STRAIN GAGES

WIPP LABORATORY EXPERIMENT
WITH SHAL SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE

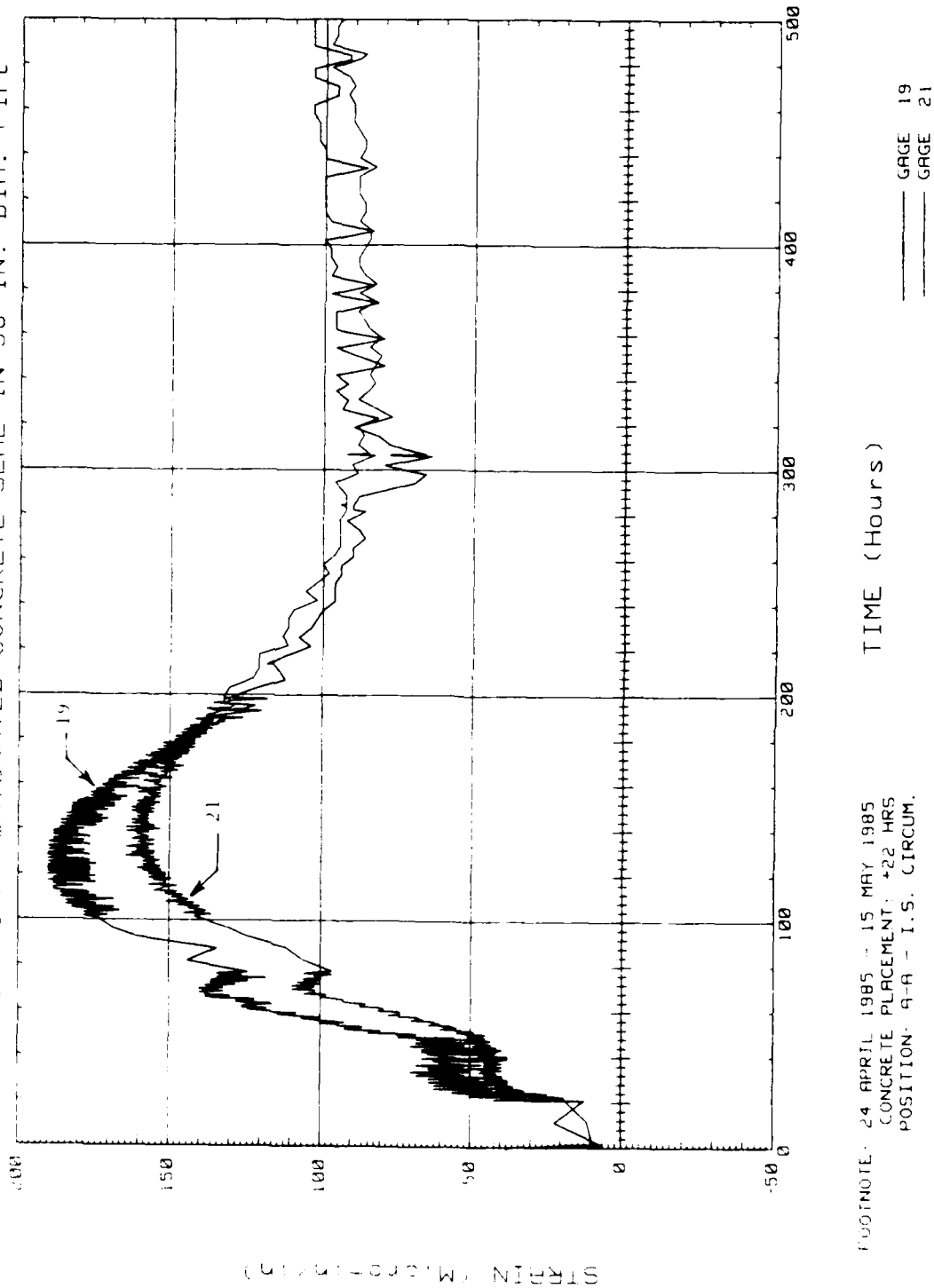
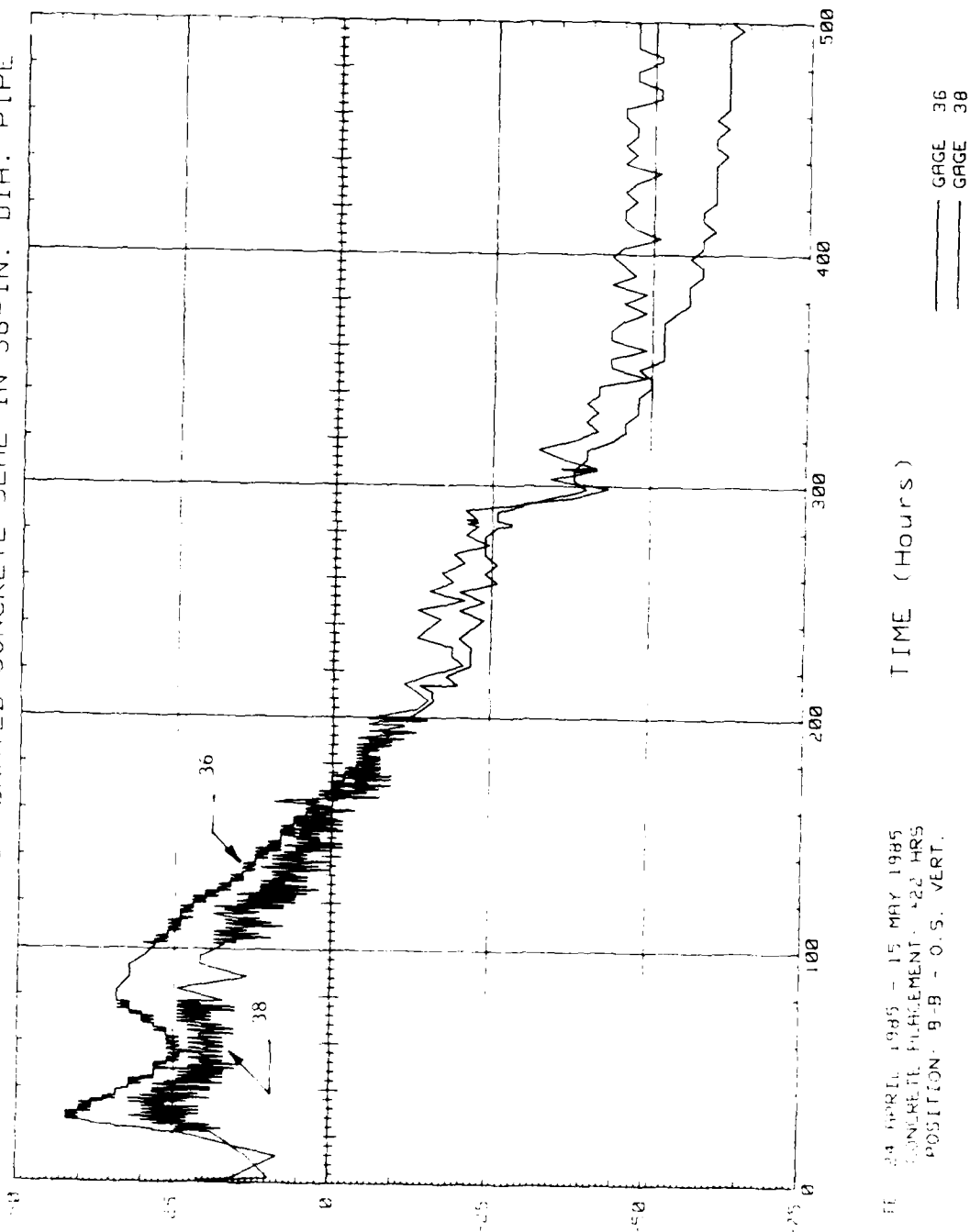


Figure 19. SR-4 type strain gages 19 and 21

SR-4 TYPE STRAIN GAGES

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE

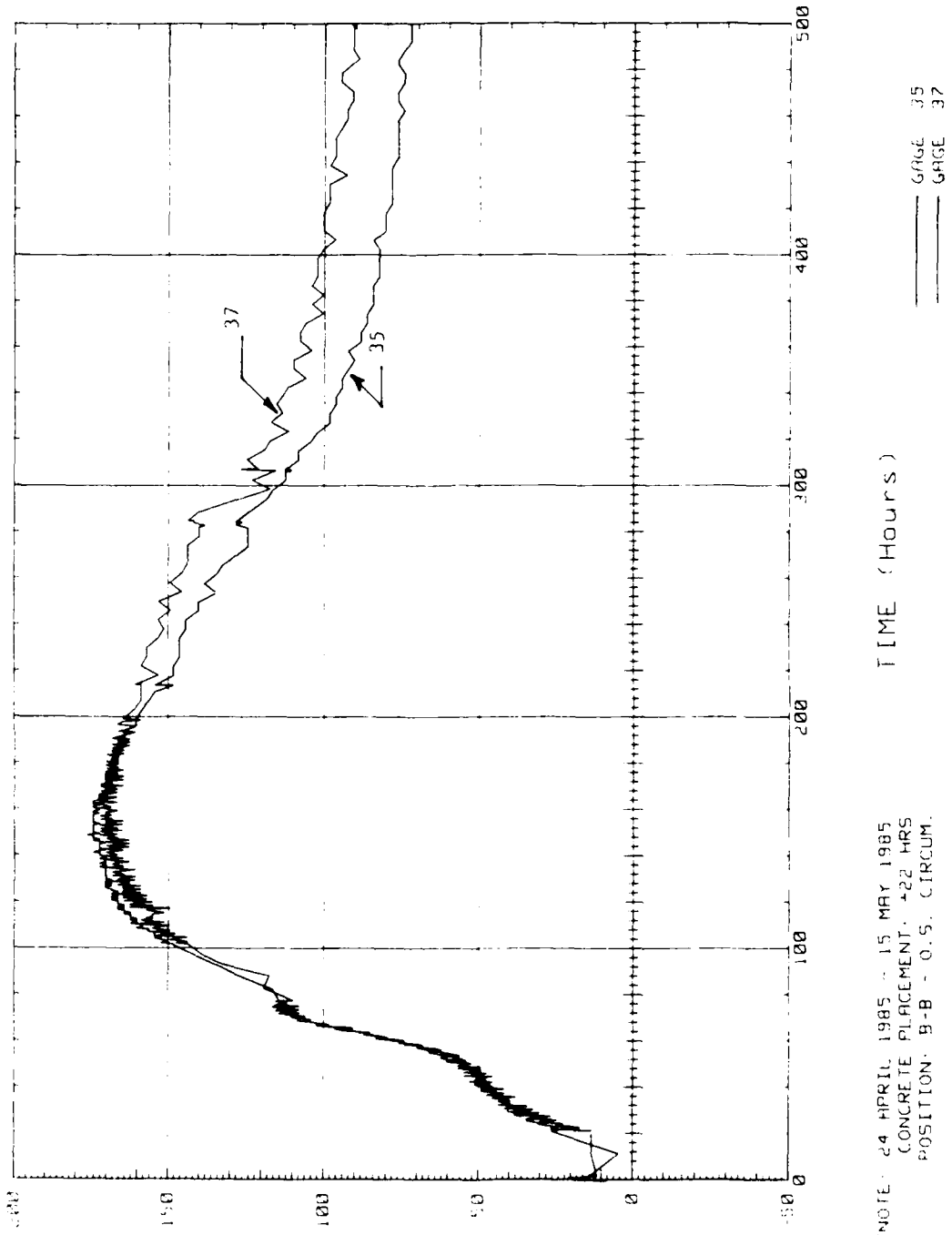


24 APRIL 1985 - 15 MAY 1985
CONCRETE PLACEMENT - 122 HRS
POSITION - B-B - 0.5. VERT.

Figure 20. SR-4 type strain gages 36 and 38

SR-4 TYPE STRAIN GAGES

WIPP LABORATORY EXPERIMENT
WITH SPLIT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE

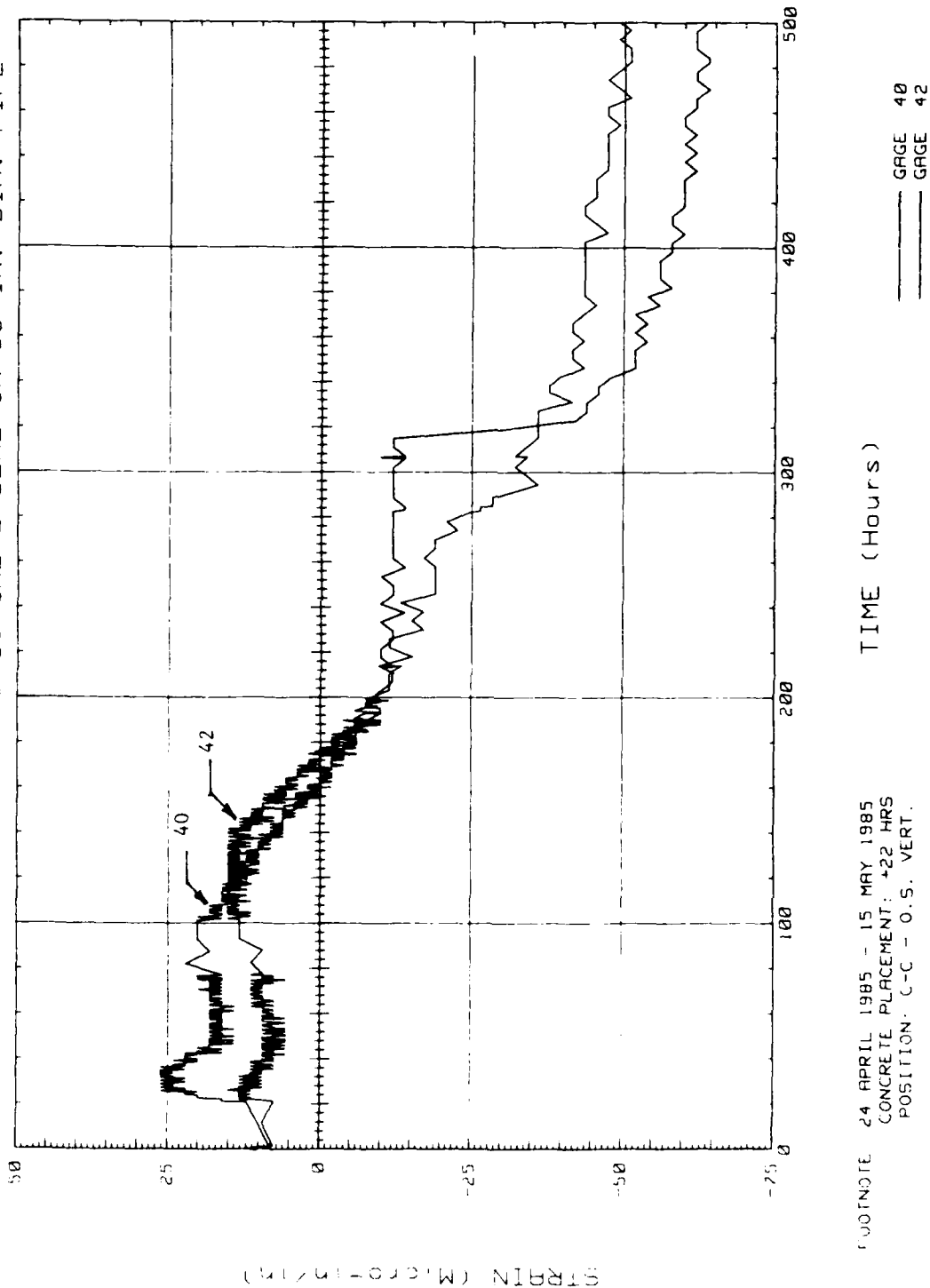


FOOTNOTE: 24 APRIL 1985 - 15 MAY 1985
CONCRETE PLACEMENT: +22 HRS
POSITION: B-B - 0.5. CIRCUM.

Figure 21. SR-4 type strain gages 35 and 37

SR-4 TYPE STRAIN GAGES

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE

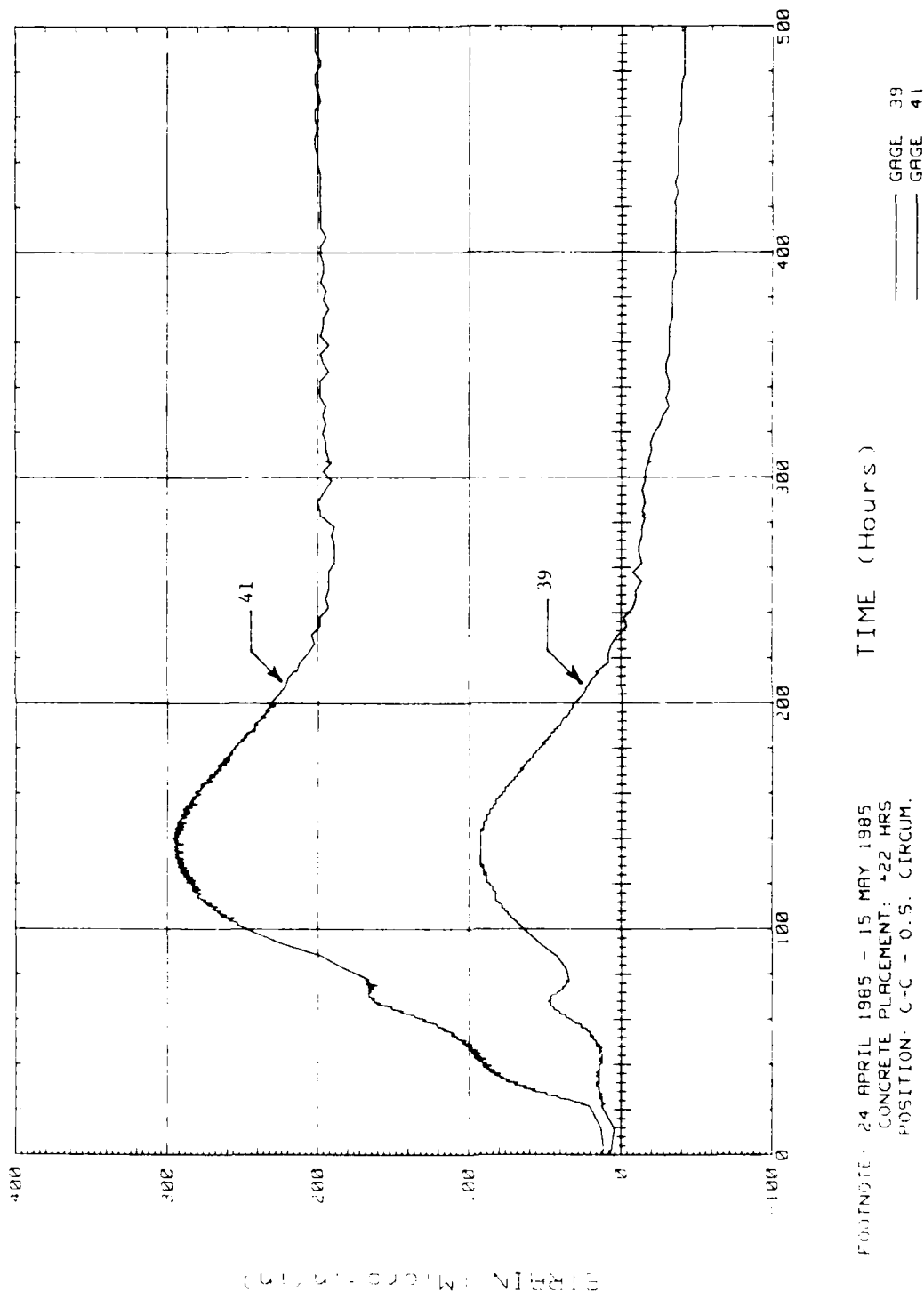


FOOTNOTE 24 APRIL 1985 - 15 MAY 1985
CONCRETE PLACEMENT: +22 HRS
POSITION: C-C - 0.5. VERT.

Figure 22. SR-4 type strain gages 40 and 42

SR-4 TYPE STRAIN GAGES

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE

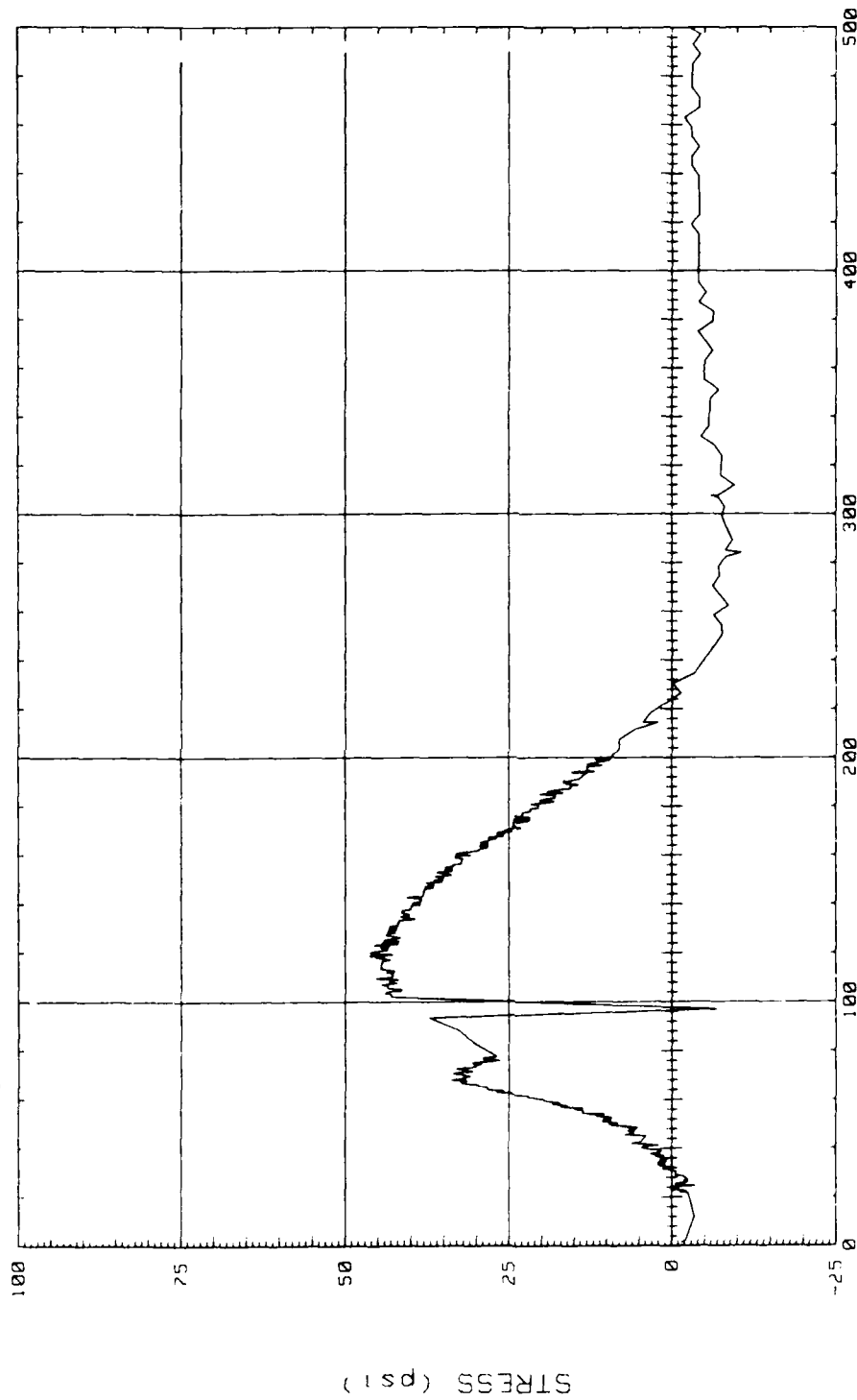


FOOTNOTE: 24 APRIL 1985 - 15 MAY 1985
CONCRETE PLACEMENT: +22 HRS
POSITION: C-C - 0.5. CIRCUM.

Figure 23. SR-4 type strain gages 39 and 41

CARLSON STRESS GAGE

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE



FOOTNOTE: 24 APRIL 1985 - 15 MAY 1985
CONCRETE PLACEMENT: +22 HRS
POSITION: A-A - RADIAL

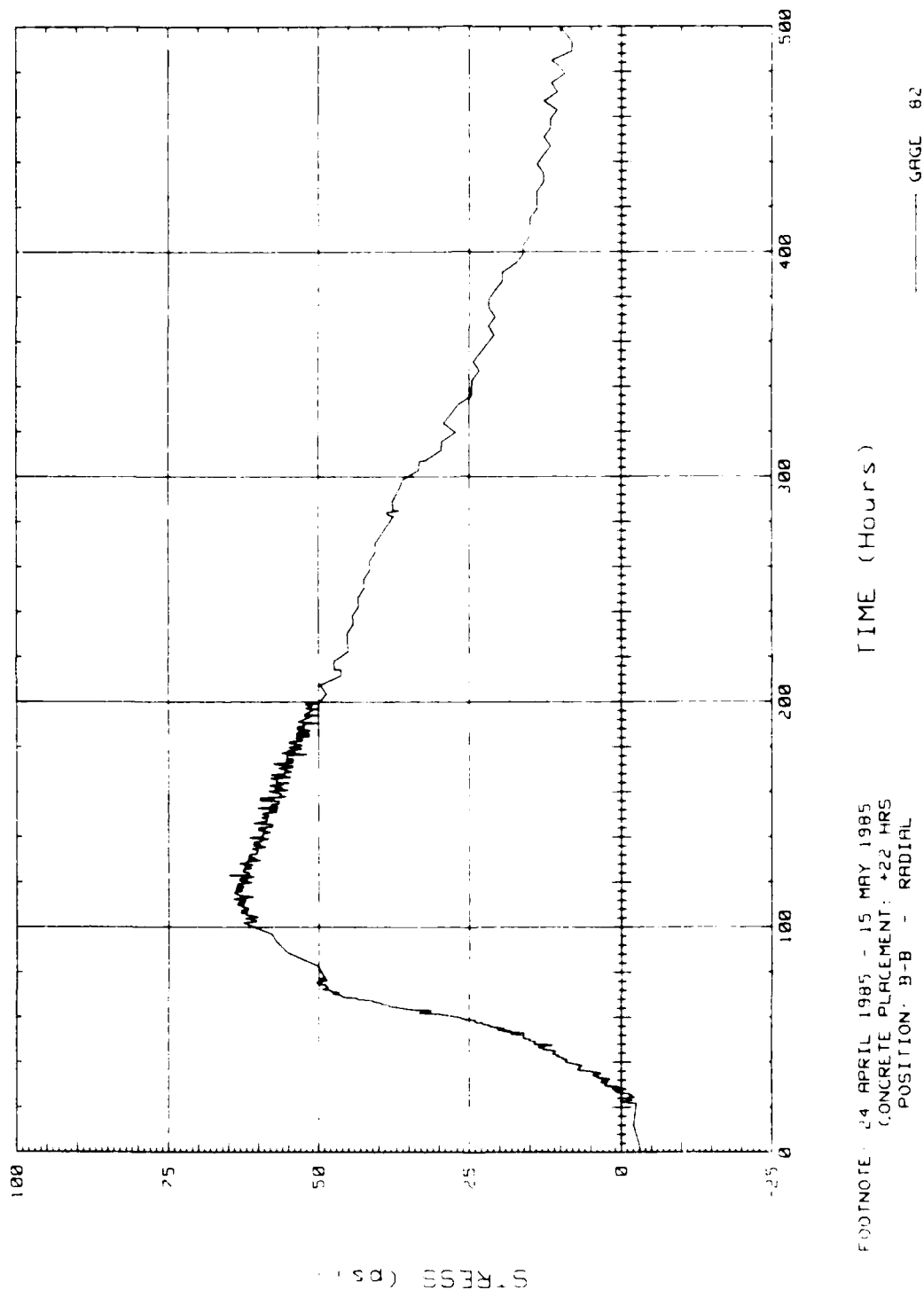
TIME (Hours)

— GAGE 84

Figure 24. Carlson stress gage 84

CARLSON STRESS GAGE

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE

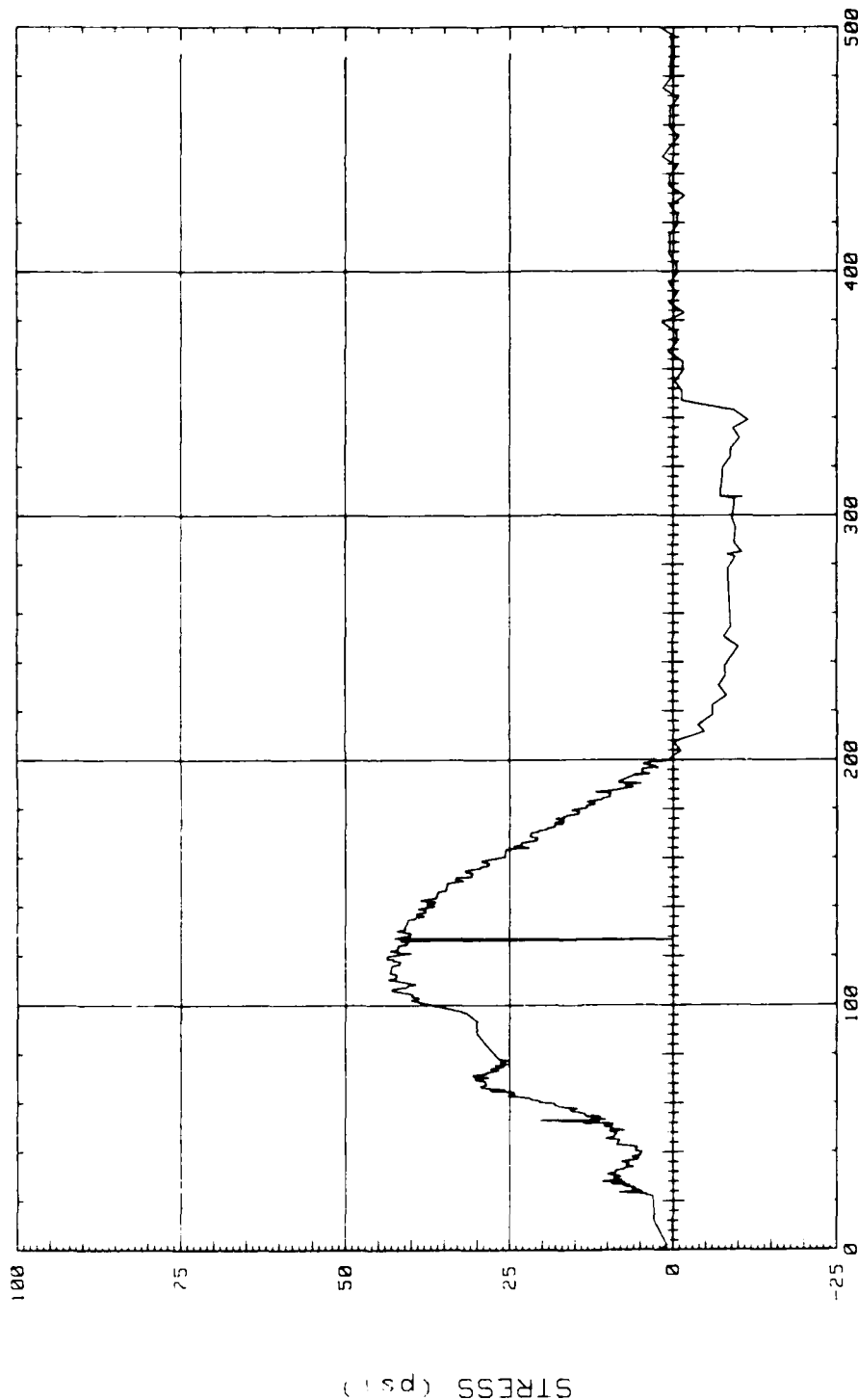


FOOTNOTE: 24 APRIL 1985 - 15 MAY 1985
CONCRETE PLACEMENT: +22 HRS
POSITION: B-B - RADIAL

Figure 25. Carlson stress gage 82

CARLSON STRESS GAGE

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE



FOOTNOTE: 24 APRIL 1985 - 15 MAY 1985
CONCRETE PLACEMENT: +22 HRS
POSITION: C-C - RADIAL

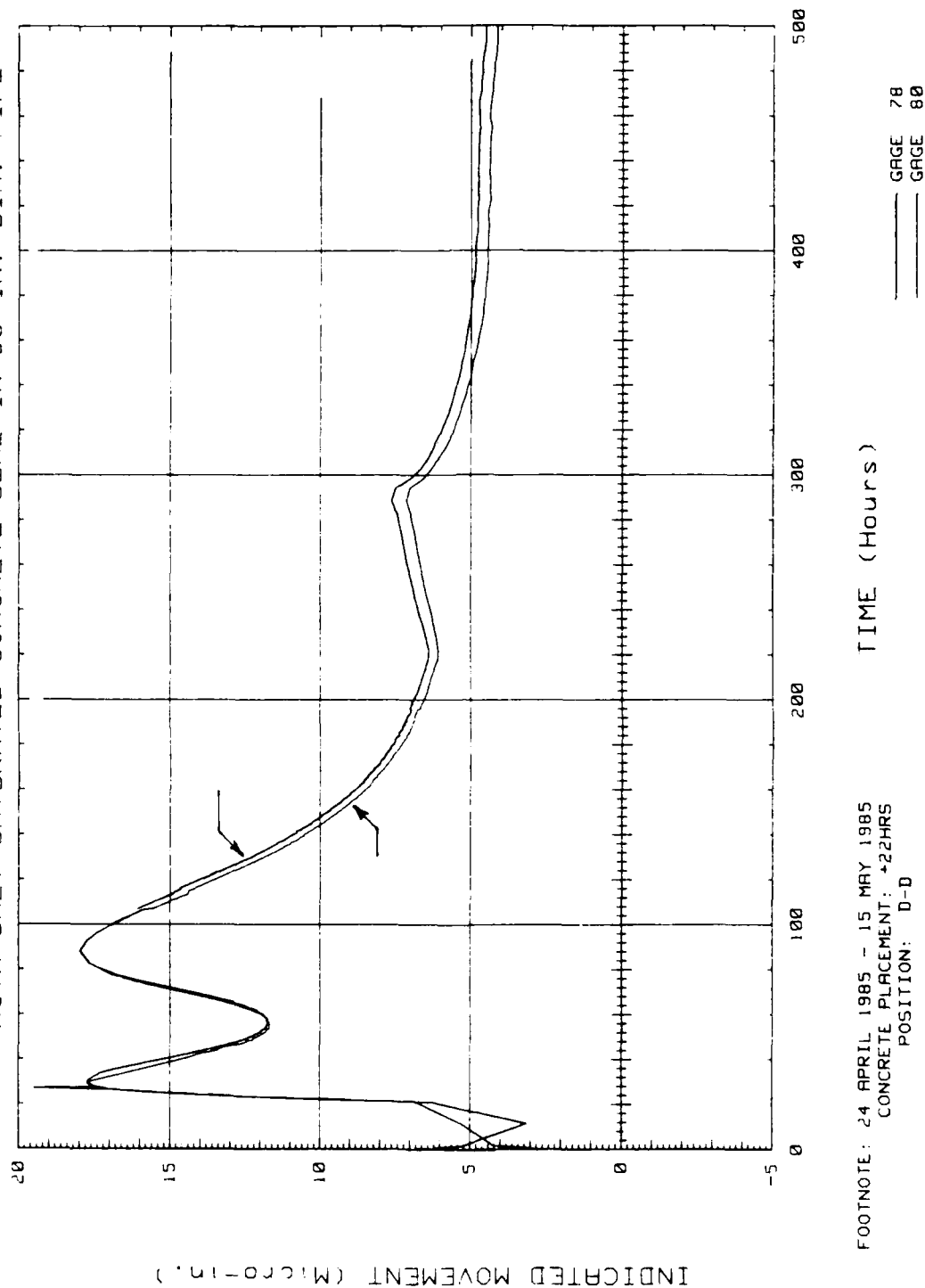
TIME (Hours)

— GAGE 86

Figure 26. Carlson stress gage 86

CARLSON JOINT METERS

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE



FOOTNOTE: 24 APRIL 1985 - 15 MAY 1985
CONCRETE PLACEMENT: +22HRS
POSITION: D-D

Figure 27. Carlson joint meters, gages 78 and 80

THERMOCOUPLES

WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE

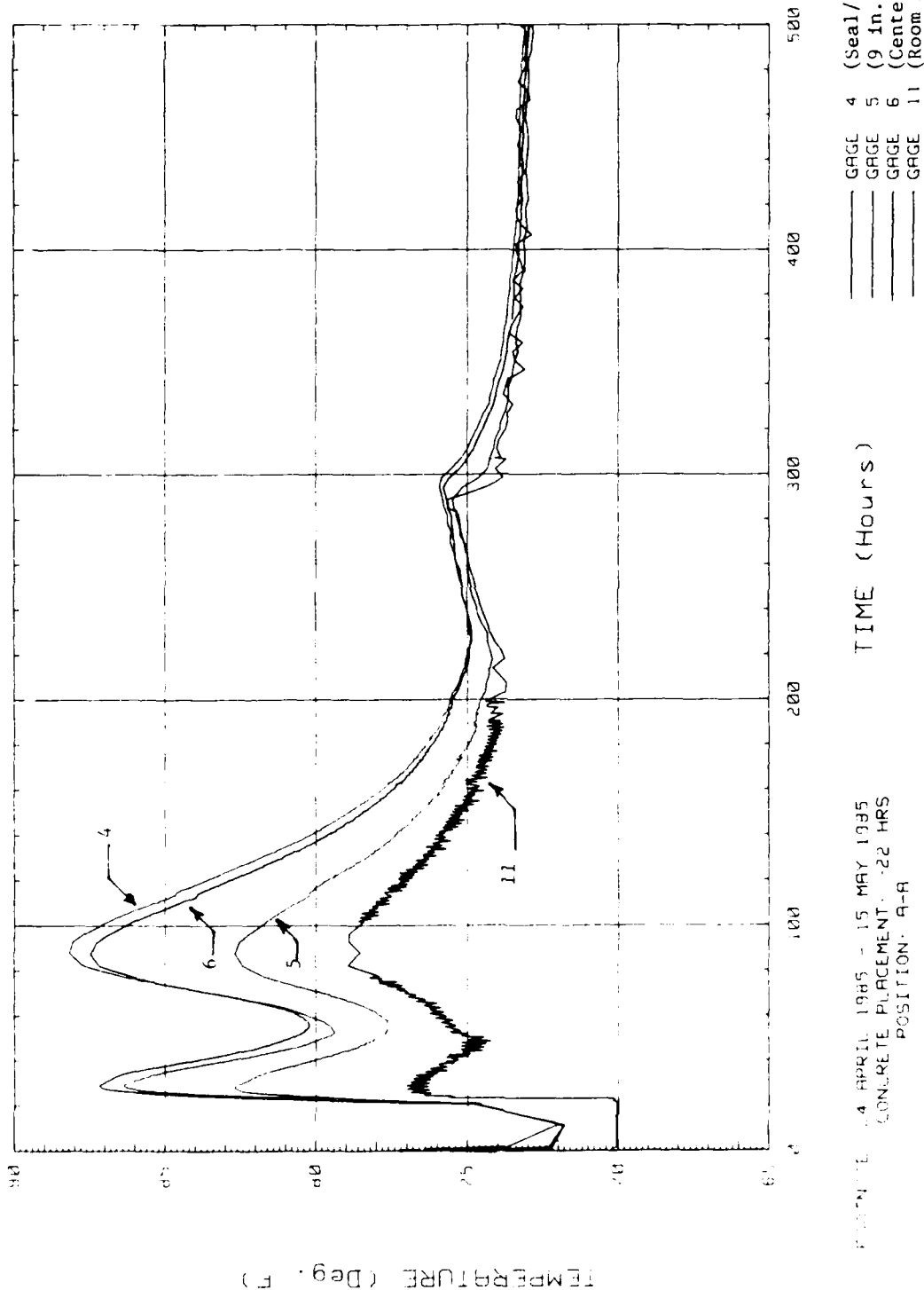
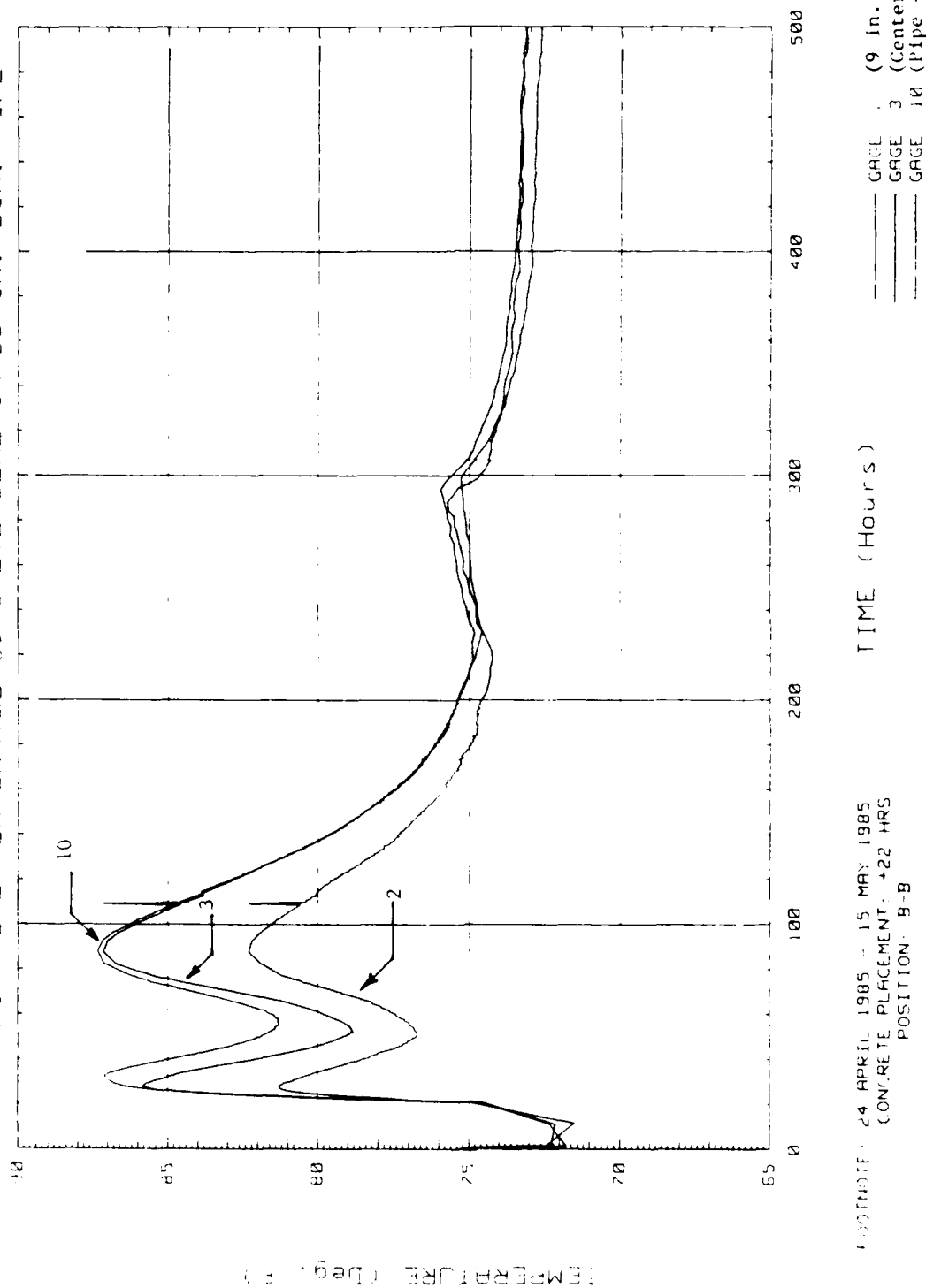


Figure 28. Thermocouples, gages 4, 5, 6 and 11

THERMOCOUPLES

WIPP LABORATORY EXPERIMENT
 WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE



FOOTNOTE: 24 APRIL 1985 - 15 MAY 1985
 (CONCRETE PLACEMENT: +22 HRS
 POSITION: B-B

Figure 29. Thermocouples, gages 2, 3 and 10

THERMOCOUPLES

WIPP LABORATORY EXPERIMENT
WITH SALT SATURATED CONCRETE SEAL IN 36-IN. DIA. PIPE

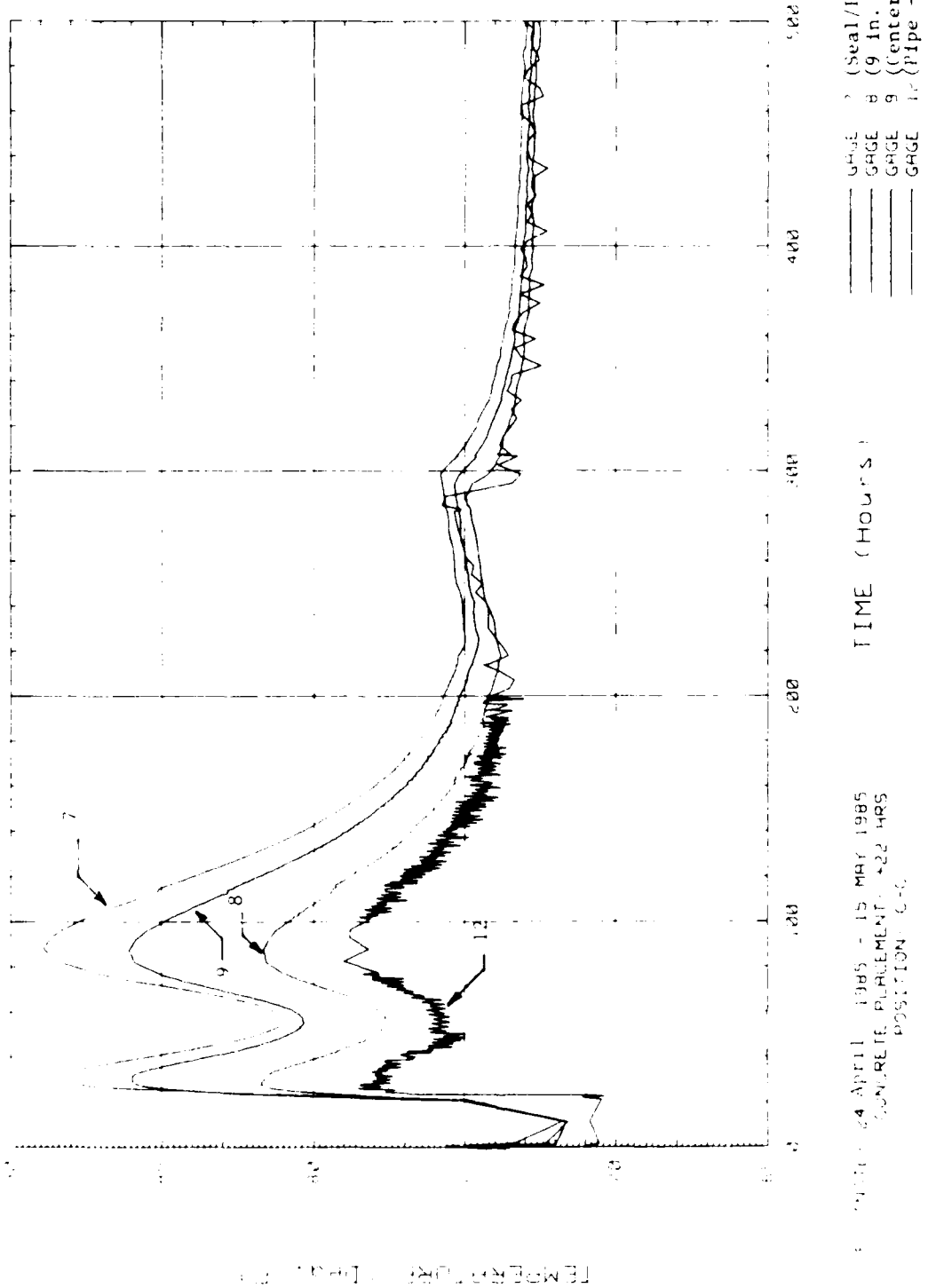


Figure 30. Thermocouples, gages 7, 8, 9 and 12

PART III: FIELD PHASE

Test Plan

36. Following the comprehensive laboratory experiment described in Part II of this report, WES fielded an instrumentation experiment to measure temperature, stress, and strain in salt-based concrete seal in vertical boreholes at the Waste Isolation Pilot Plant (WIPP) facility near Carlsbad, New Mexico. This experiment is a part of the Test Series A of the Small Scale Seal Performance Tests and locations are as specified, except where noted, by the Sandia test plan (Stormont, 1985).

Test Configuration

37. Three sizes of borehole seals were instrumented by WES personnel: 6 in. in dia., 1 ft in length; 16 in. in dia., 2 ft in length; and 36 in. in dia., 3 ft in length. The gages selected were essentially the same as used in the laboratory experiment except the thermocouples were encased type E, chromel-constantan, rather than nonencased Type T, copper-constantan. Data for the 6-, 16-, and 36-in. dia. instrumented holes and concrete seals are shown in Tables 1, 2, and 3, respectively. Figures 31, 32, and 33 show the locations of the gages by levels in the respective holes.

38. Prior to embedment, the stress, strain, and temperature gages were assembled on a mounting support tree or jig for each of the three hole diameters. Figures 34-36 are photographs showing the three mounting support jigs or trees with gages. All gages to be installed by WES were mounted on the trees, with the exception of the Carlson Stress and Joint Meters and the SR4 strain gages. The electrical lead wires were tailored such as to guide them along the radial support rods to the center post and up the center post to a point above the proposed height of the concrete. An epoxy gas block was fabricated around the center post and lead wires in order to minimize leakage of gas or brine water during the future permeability tests.

39. The Carlson Stress Meters were bonded to the side wall of 36-in. diameter hole at their predetermined levels using a fast-setting epoxy resin. The Carlson Joint Meter was screwed into the steel-mounting socket which had been previously epoxied into a recessed hole bored into the wall of the 36-in.

Table 1
Data on Gages Installed by WES
in 6-in. Diameter Seal Emplacement Hole MAE 11

Sandia Gage No.	Level in Concrete Seal	Type of Gage	Manufacture's No.	Type & Direction of Measurement
MA111-1	1	Ailtech Strain	WES- 7	Radial Strain
-2	2	" "	- 8	" "
-3	3	" "	- 9	" "
MA112-1	1	" "	-10	Circumferential Strain
-2	2	" "	-11	" "
-3	3	" "	-12	" "
MA131-1	1	SNL Pressure	J09	Radial Stress
-2	2	" "	J10	" "
-3	3	" "	J11	" "
MA151-1	1	Thermocouple, Type E	WES-19	Temperature Near Wall
-2	2	" "	-20	" " "
-3	3	" "	-21	" " "
MA152-1	1	" "	-22	Temperature at Center
-2	2	" "	-23	" " "
-3	3	" "	-24	" " "

Note: 1. Level 1 is 4-1/4 in. below top of 13-1/4-in. long seal
Level 2 is 7-1/4 in. below top of 13-1/4-in. long seal
Level 3 is 10-1/4 in. below top of 13-1/4-in. long seal

Table 2
Data on Gages Installed by WES
in 16-in. Diameter Seal Emplacement Hole MAE 21

Sandia Gage No.	Level in Concrete Seal	Type of Gage	Manufacture's No.	Type & Direction of Measurement
MA211-1	1	Carlson Strain	4741	Radial Strain
-2	2	" "	4742	" "
-3	3	" "	4743	" "
MA213-1	1	" "	4744	Circumferential Strain
-2	2	" "	4745	" "
-3	3	" "	4746	" "
MA212-1	1	Ailtech Strain	WES-1	Radial Strain
-2	2	" "	" -2	" "
-3	3	" "	" -3	" "
MA214-1	1	" "	" -4	Circumferential Strain
-2	2	" "	" -5	" "
-3	3	" "	" -6	" "
MA231-1	1	SNL Pressure	J-06	Radial Stress
-2	2	" "	J-07	" "
-3	3	" "	J-08	" "
MA251-1	1	Thermocouple, Type E	WES-25	Temperature Near Wall
-2	2	" "	-26	" " "
-3	3	" "	-27	" " "
MA252-1	1	" "	-28	Temperature at Center
-2	2	" "	-29	" " "
-3	3	" "	-30	" " "

Note: Level 1 is 6-1/2 in. below top of 24-1/2-in. long seal
Level 2 is 12-1/2 in. below top of 24-1/2-in. long seal
Level 3 is 18-1/2 in. below top of 24-1/2-in. long seal

Table 3
Data on Gages Installed by WES
in 36-in. Diameter Seal Emplacement Hole MAE 31

Sandia Gage No.	Level in Concrete Seal	Type of Gage	Manufacture's No.	Type & Direction of Measurement
MA301	2	Carlson Joint Meter	J-91	Strain Across Interface
MA311-1	1	Carlson Strain Meter	4654	Radial Strain
-2	2	" " "	4655	" "
-3	3	" " "	4656	" "
MA313-1	1	" " "	4657	Circumferential Strain
-2	2	" " "	4739	" "
-3	3	" " "	4740	" "
MA312-1	1	Ailtech Strain Gage	WES-13	Radial Strain
-2	2	" " "	-14	" "
-3	3	" " "	-15	" "
MA314-1	1	" " "	-16	Circumferential Strain
-2	2	" " "	-17	" "
-3	3	" " "	-18	" "
MA331-1	1	SNL Pressure Gage	J-03	Radial Stress
-2	2	" " "	J-04	" "
-3	3	" " "	J-05	" "
MA332-1	1	Carlson Stress Meter	C620	" "
-2	2	" " "	C621	" "
-3	3	" " "	C623	" "
MA351-1	1	Thermocouple, Type E	WES-31	Temperature Near Wall
-2	2	" " "	-32	" " "
-3	3	" " "	-33	" " "
MA352-1	1	" " "	-34	Temperature at Center
-2	2	" " "	-35	" " "
-3	3	" " "	-36	" " "
MA315-1	1	SR-4 Strain Gage	WES-37	Vertical Strain
-2	2	" " "	-38	" "
-3	3 ²	" " "	-39	" "
MA316-1	1	" " "	-40	Circumferential Strain
-2	2	" " "	-41	" "
-3	3 ²	" " "	-42	" "

Note: 1. a. Level 1 is 10-1/2 in. below top of 37-1/2-in. long seal
b. Level 2 is 19-1/2 in. below top of 37-1/2-in. long seal
c. Level 3 is 28-1/2 in. below top of 37-1/2-in. long seal
2. & 3. Gages located 1-1/2" above that indicated in note 1.c.

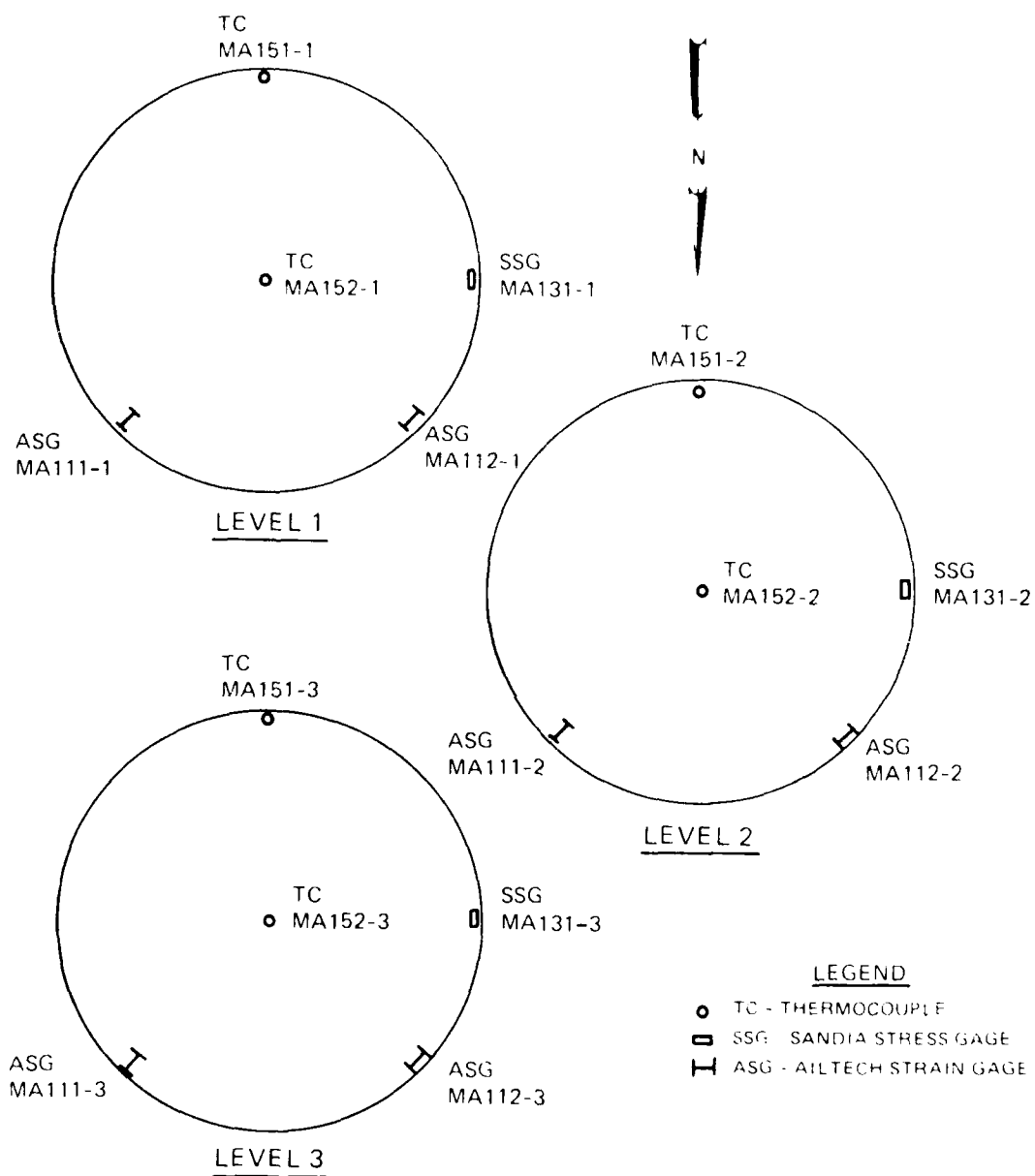


Figure 31. Position of WES installed gages (as built) for emplacement MAE11

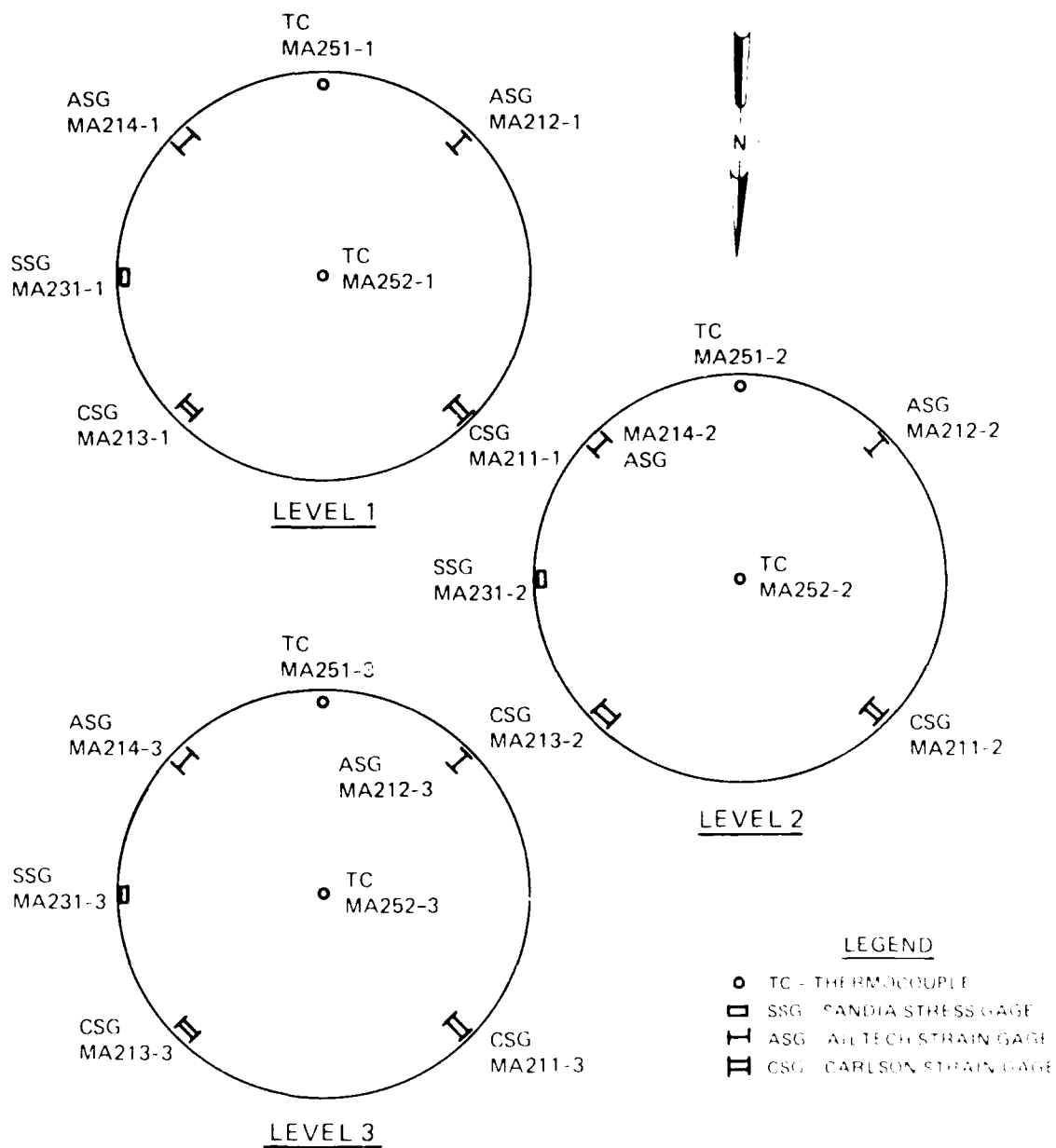


Figure 32. Position of WES installed gages (as built) for emplacement MAE21

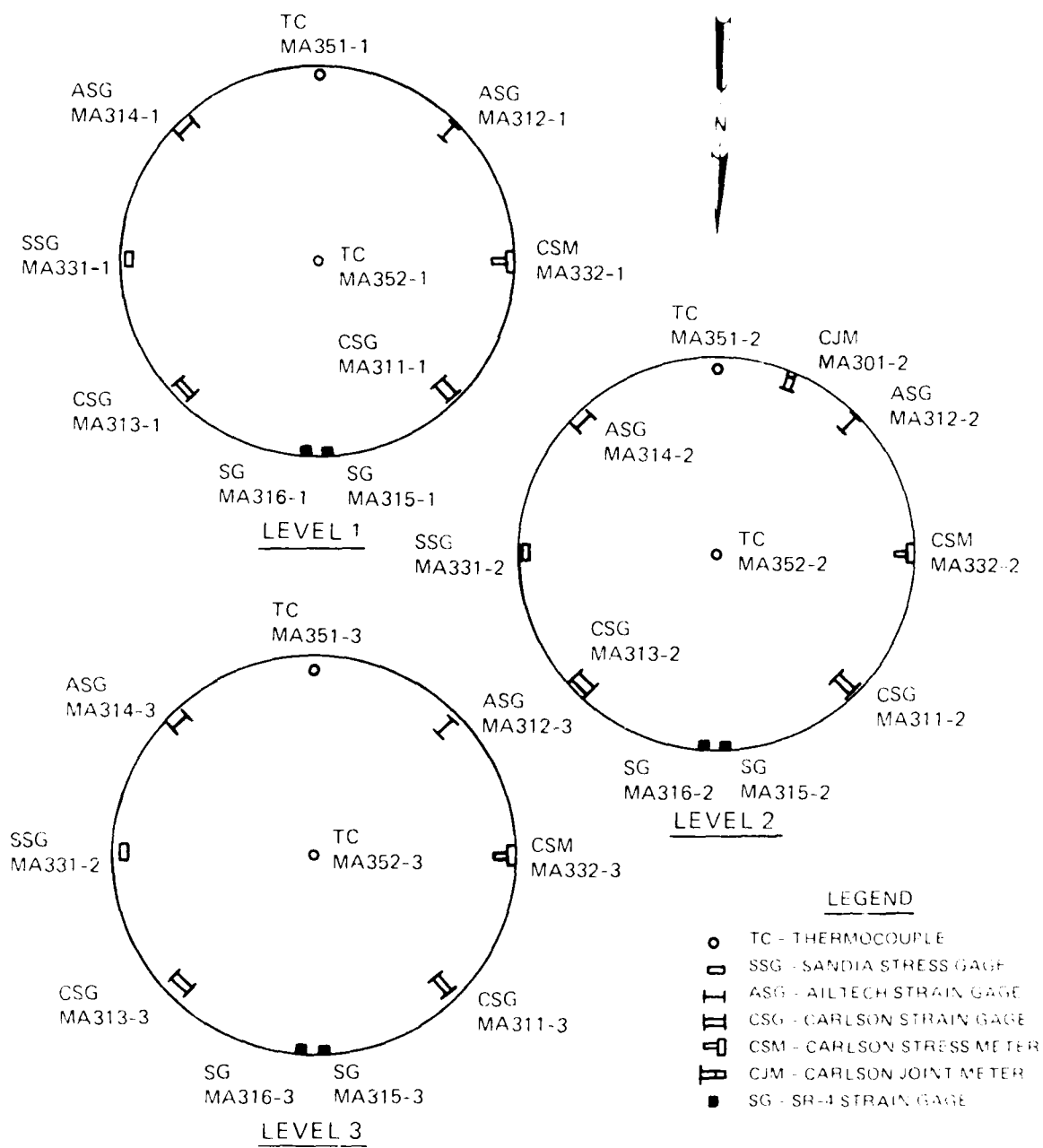


Figure 33. Position of WES installed gages (as built) for emplacement MAE31

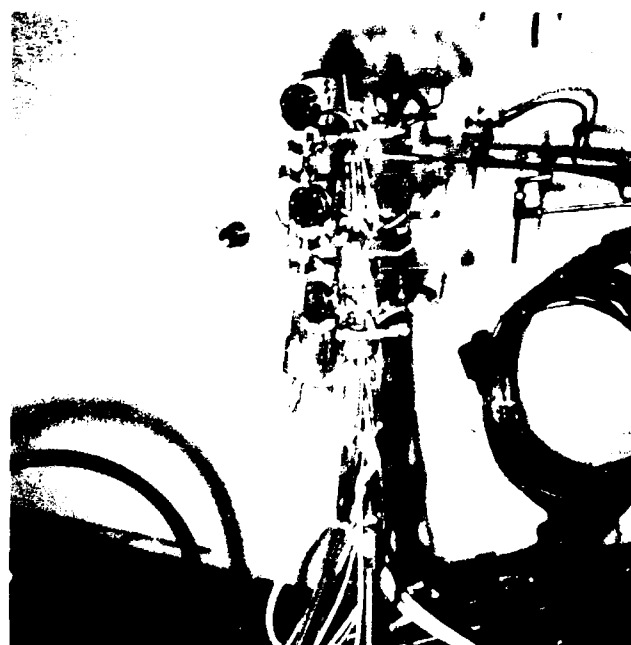


Figure 34. 6-in. diameter assembly support tree with gages

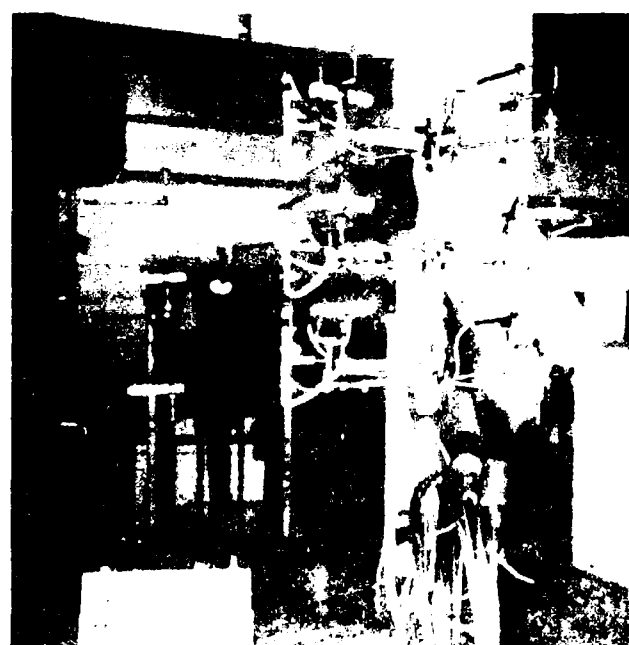


Figure 35. 16-in. diameter assembly support tree with gages

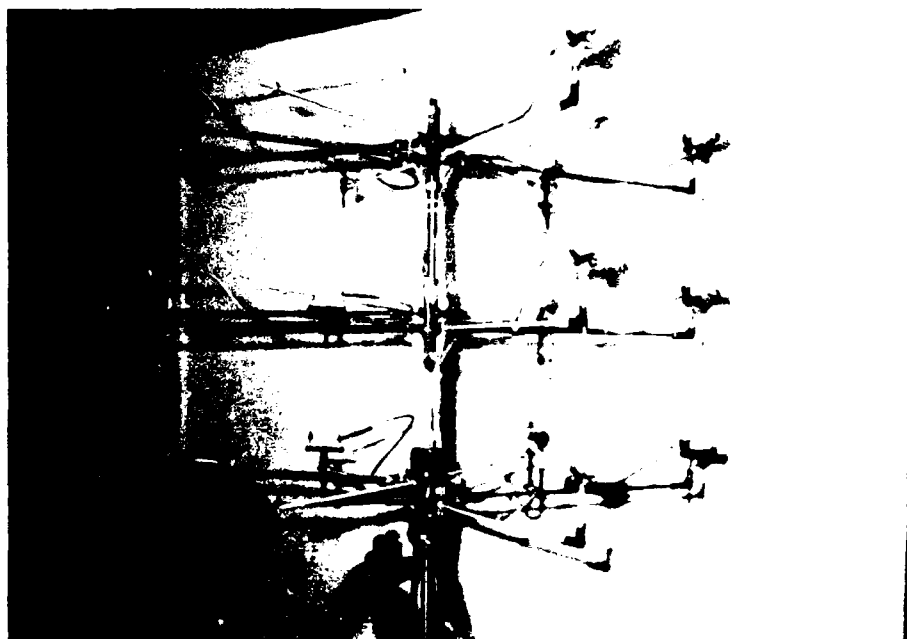


Figure 36. 36-in. diameter assembly support tree with rages



Figure 37. 36-in. diameter borehole seal hole with Carlson joint and stress meters

hole. Figure 37 is photograph of the 36-in. dia. hole with the Carlson Joint and stress meters installed.

40. The gages were installed on 22 & 23 July 1985. The only deviations from the locations specified in the Sandia test plan (Stormont 1985) are as follows:

- a. Strain gages MA315-3 and MA316-3 were located 1-1/2 in. above that shown in order to avoid a clay seam.
- b. The gage assembly for the 6-in. hole (MA11) was inadvertently inverted resulting in gages being located in the mirror image with respect to their positions as specified by the test plan. These changes are reflected in the as built configuration, Figure 13.

41. After installation, the gage cables were connected to the instrumentation cables leading to the A-3 data acquisition facility housing the signal conditioning equipment. Upon completion of the cable hook-up, all gages were checked for functional operation. A minicomputer on the surface controls the data acquisition equipment and collects and stores the test data.

Conduct of Test

42. The concrete used for Test Series A was developed in the CTD for WIPP experiments, as described by Wakeley and Walley (1986). The concrete was placed in the instrumented holes beginning at approximately 6:00 a.m., 30 July 1985. The concrete was placed using a tremie tube at a slow rate so as to minimize disturbance of gages. However, during placement the gage assembly tree was shoved slightly in a north easterly direction, pushing several gages against the hole wall. No detectable damage was observed. During and after placement, the concrete was vibrated in selected areas that would cause the least disturbance of the gages.

43. After emplacement, the gages were monitored by Sandia instrumentation personnel using the previously mentioned data acquisition system developed for the WIPP in situ tests reported by McIlmoyle, Matalucci, and Ogden (1986).

Preliminary Test Results

44. Early data plots have indicated that some of the gages were not performing as expected. A detailed look is being taken at both the measuring

system and possible gage malfunction. An analysis has not been made of the preliminary data. However, it is obvious from preliminary plots of data that most of the gages are performing as expected.

PART IV: SUMMARY AND CONCLUSIONS

45. An instrumentation program was developed for the purpose of monitoring the state of stress and deformation in a concrete borehole seal for use underground at the WIPP. A laboratory development program was conducted both to select gages for a field experiment and to measure for evaluation purposes the stresses and strains in an expansive salt saturated concrete plug, 3 ft in diameter by 3 ft long, cast in a 34-3/4-in. I.D. by 5-ft long steel casing with 5/8-in. wall thickness. A total of 33 internal gages were placed in the concrete and 9 gages were located on the external surface of the steel casing. The gages were strategically located to provide the maximum useful information for thermal and structural analysis for the plug. The gages used were: Carlson stress meters; Sandia pressure cells; Carlson strain meters; Ailtech strain meters; SR-4 strain gages; and type T thermocouples.

46. Based on their performance in the laboratory program, gages were selected for installation in a field experiment at the WIPP. Three vertical borehole seals, 6-, 16-, and 36-in. diameter holes were instrumented. Carlson stress meters and Sandia pressure cells were used to measure the stress in the seal. Carlson strain meters and Ailtech strain meters measured the strain in the seal. SR-4 strain gages were fixed to the borehole wall to measure strain at the seal-rock interface. Type E thermocouples were used to measure the temperature in the seal and at the seal-rock interface. The gages were pre-assembled on a mounting fixture, with the exception of the Carlson joint and stress meters and the SR-4 gages, and positioned in the holes prior to the placement of the concrete. As in the laboratory experiment, the gages were strategically located to provide the optimum description of the concrete seal performance.

47. Some of the conclusions that can be drawn from the study include:

- a. The salt-based concrete does indeed expand as the design predicted.
- b. Early data indicate that the interface seal was tight at least over the short monitoring period in a vertical hole.
- c. Electronic gages can be used to measure the performance of a concrete seal.

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